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ANNUAL REPORT

OF THE

DIRECTOR

OF

HARVARD COLLEGE OBSERVATORY.

PRESENTED TO THE VISITING COMMITTEE
NOVEMBER 26, 1877,

BY

PROFESSOR EDWARD C. PICKERING.

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REPORT.

To the Visiting Committee of the Harvard College Observatory:—

GENTLEMEN,—In presenting this, my first Annual Report as Director of the Harvard College Observatory, it seems desirable to state the general plan in accordance with which our work will hereafter be conducted. I shall then show what has been done during the past year to carry out this plan, and in what directions an extension seems desirable. The Observatory possesses two instruments of the largest size and finest quality,—an equatorial of fifteen inches aperture, and a meridian circle whose telescope has an aperture of eight inches. Their great cost renders it extremely desirable that both these instruments should be kept in active use. For reasons which will be given elsewhere (Appendix A), it has been decided to devote the large telescope mainly to photometry, a subject promising results of great scientific, as well as popular, interest. It is somewhat remarkable that this field, at least as regards the minuter heavenly bodies, should have been so long neglected. Our knowledge of the amount of light they emit is based almost entirely on simple eye estimates. Material changes in the work of the meridian circle seem undesirable. All the work heretofore done with it has, however, been dependent on a standard catalogue of stars observed at the Pulkova Observatory, which is provisionally accepted as correct. One of the greatest defects of modern astronomical observations is the systematic error thus engrafted from one catalogue into another. It is accordingly proposed, as soon as the present work with the meridian circle is completed, to undertake the determination of the absolute position of a certain number of standard stars. This catalogue is to be made wholly independent of all previous observations; and, by the introduction of some improved methods, it is hoped that an increased degree of accuracy will be attained.

BOOKS AND MANUSCRIPTS.

A large amount of time during the past year has been devoted to the work of reorganization. It seemed desirable to make a careful examination of the manuscripts, books, and instruments belonging to the Observatory. The record-books, containing all the equatorial and miscellaneous observations made since the establishment of the Observatory, have been numbered according to a system introduced by the late Professor Bond. They are arranged on shelves in the vestibule of the main entrance to the building, so that, in case of fire, a few minutes would be sufficient to remove them to a place of safety. The unbound manuscripts have been boxed and labelled, and deposited on shelves in the cellar, where they may be readily consulted when desired. The remaining copies of the various volumes of the Annals have been similarly boxed, and placed with the manuscripts. Extra copies of reports and of various scientific papers have also been collected, and arranged in order. The Library has much outgrown the room allotted to it. All the duplicates have been removed, and placed with the meteorological and magnetic observations in the Prime Vertical Room. The older volumes of some of the periodicals have been placed on shelves in the entry over the Library. Many of the sets proved to be incomplete, and their deficiencies have been supplied, as far as possible. A large number of volumes have been bound, but much more remains to be done in this direction. The pamphlets which have collected since 1857 have been arranged according to subjects, and bound in volumes, as nearly as possible in conformity with the plan adopted by Professor Bond. The acknowledgment of books and pamphlets presented to the Observatory has been rendered systematic, by the preparation of circular letters for this purpose. An examination of the Library showed that it was deficient in many of the later works on astronomy. A list of the books which the Observatory needed was prepared, and each of the assistants was requested to note the deficiencies he had observed. Most of these books have since been purchased. It is very desirable that a definite sum should be applied yearly to the Library, for new books and binding, and that our corps of assistants should be so far enlarged that the charge of the Library may be assigned to one of them as a prominent duty. A considerable change in the arrangement of the books seems also desirable.

PUBLICATIONS.

Up to the close of the last year, the following volumes of our Annals had been distributed: Vol. I., parts 1 and 2; Vol. II., parts 1 and 2; Vol. III; Vol. IV., part 1; and Vol. V. Vol. VI. (Zone Observations by Professor Bond in 1859–60) and Vol. VII. (Observations of Sun Spots in 1847–49) had been printed, but not distributed. Vol. VIII. (History of the Observatory and Astronomical Engravings) was completed in the latter part of 1876. An immediate distribution of these three volumes seemed therefore desirable. The lists of the recipients of the former volumes of the Annals were very imperfect, and required serious changes. A new list was therefore prepared, and entered in a book ruled in columns, to show what volumes were sent to each address. This was filled out, as far as possible, from the former lists; and new volumes when sent are entered in it. It is found necessary to very much restrict the number of private individuals to whom the Annals are sent. Precedence is given to active observatories, learned societies, public libraries, professional and amateur astronomers. These require so many copies, that but few can be sent to the local friends of the Observatory. To remedy this difficulty, however, an arrangement has been effected with Messrs. H. O. Houghton & Co., publishers, by which a limited number of sets or single volumes of our Annals are offered for sale. Should the demand prove considerable, future volumes of our Annals will be offered to the public at but little more than the cost of paper and printing. A higher rate has been named for some of the older volumes, as the number on hand is barely sufficient for the future needs of the Observatory. Recognizing the general interest in the Astronomical Engravings forming the second part of Vol. VIII., Messrs. Ginn & Heath, publishers, have offered to aid in the wider distribution of this work by the issue of a new edition of the volume containing it.

I regret to state that Vol. IV., part 2, and Vol. IX., of our Annals are still unfinished. The first of these is in charge of Professor Safford, and contains the right ascensions of a catalogue of stars observed in 1862–65 with the old meridian circle. Professor Safford, in a recent note, states that but little remains to complete this work. Vol. IX. is in charge of Mr. C. S. Peirce, and contains photometric observations made by him in 1872–75. It is ready for publication, except the Preface and a photometric catalogue of stars brighter than the sixth magnitude, which will probably be published later. During the past year, Vol. X. has been published and distributed. It contains the results of observations made by Professor Rogers in 1871–72 with the new meridian circle, and gives the first results yet derived from this instrument. This volume affords an example of a plan which will be followed in our future publications, of giving not merely the results obtained, but a discussion of them, and a comparison with those obtained elsewhere.

Besides these volumes, there is a large amount of material not yet printed, especially of work with the meridian circle. The polar catalogue observed in 1872–73 is nearly ready for the press. The observations of a general catalogue for 1874–75 were completed at that time, but are not yet reduced. The observations of the Cambridge Zone are now approaching completion, and the form of publication to be adopted for them will have to be considered soon. Besides these, some of the past work of the large equatorial will probably be published; and this, with the observations of the past year, will fill a volume in itself.

It accordingly appears that the Annals distributed during the past year nearly equal in amount all those issued by my predecessors, and that the unpublished observations already made will occupy an equal number of additional volumes; in other words, the material as yet unpublished equals in amount all that issued from the establishment of the Observatory to the end of the year 1876. The accumulation of unpublished material is very objectionable, as, in case of fire, much valuable work might be lost. Moreover, when observations are not immediately reduced, their publication is attended with much greater difficulty, especially when, as often happens, the work passes into other hands. In many cases, the delay reduces the value of the results, which may meanwhile be obtained elsewhere. As other observations are now accumulating, at least as rapidly as at any previous time in the history of the Observatory, it seems essential that active measures should be taken for immediate publication. The great difficulty is the labor of preparing the work for the press, and it is desirable that at least one assistant should be attached to the Observatory, whose principal duty it shall be to assist in this work. Even after the older observations are published, a volume should be issued almost every year, that the results obtained may become immediately available. Should this be accomplished, a considerable saving might be effected by purchasing the necessary type, and keeping a type-setter constantly employed in the Observatory building. The printing and publishing of the Annals would, of course, be done elsewhere.

SCIENTIFIC WORK.

The scientific work done with the large equatorial and meridian circle is detailed in Appendices A and B; it is only necessary, therefore, to give a summary of it here. The first of these instruments has been mainly devoted to photometric work. Accurate photometric measurements have been obtained for the first time of several of the faintest known objects. Thus, four hundred measurements have been made of the brightness of the outer satellite of Mars, and about seventy of the inner satellite. Two or three wholly independent methods have been employed, and will give the true brightness with considerable precision. It is believed that no accurate measures of the brightness of these bodies have been made elsewhere. The satellites of

Jupiter and Saturn have been similarly measured. Over a hundred measures have been obtained of Hyperion, the faintest of the satellites of Saturn. To simply see this satellite is regarded as a severe test of any but the very largest telescopes. Several asteroids have been compared in brightness with Mars and Saturn. These comparisons will furnish the first satisfactory means of estimating the actual size of the smaller planets. The two components of several double stars have been compared. Some have been selected in which one component is extremely minute, so that these measurements will give a standard with which observers hereafter can compare other faint stars, and thus reduce the present vagueness of the higher magnitudes to comparative precision.

Besides the measures of the brightness of the satellites of Mars, a large number of determinations of their positions were made by Mr. Waldo. One hundred and thirty-five measures of the position angles, and ninety-two of the distances of the outer satellite, were obtained, and fifty-two of the angles and forty-three of the distances of the inner satellite. This set is believed to be second only to that made by Professor Hall, with the 26-inch telescope at Washington. Another observation of the outer satellite of Mars, of some general interest, related to its color. A comparison with Mars, under circumstances more favorable than would probably be attained elsewhere, showed that the red color of the primary was not possessed by the satellite.

A beginning has been made of a direct comparison of the light of the sun and stars, the latter being observed during the day with the full aperture of 15 inches, while the sun is reduced, first by refraction through a small quartz sphere, and then by observing it in a small auxiliary telescope. It is proposed thus to reduce all our photometric measurements to a common unit, — the light of the sun.

The near approach of Mars and Saturn and of Jupiter and Venus afforded a good opportunity for a photometric comparison. This has been done in the intervals of other work, and has given several hundred measurements of their relative brightness. The polarization of the light of Venus has been rendered obvious at the same time.

As detailed in Appendix B, the principal work of the meridian circle has been as follows: Continuation of the observations of the Cambridge Zone. This is the share taken by the Observatory in the determination of the accurate position of all stars of the first nine magnitudes contained in the Northern Hemisphere. These form a large part of Argelander's great catalogue called the Durchmusterung, the revision of which has recently been undertaken by several Observatories acting in concert. The only portion of this work which is being done in this country is the Cambridge Zone, and includes the stars between 50° and 55° north. A large portion of these stars are so situated that they are best observed during the autumn months; but Professor Rogers, by special efforts this autumn, has so far reduced the number still to be observed, that it is not improbable that this work may be completed during the coming year.

During the recent opposition of Mars, observations were obtained of this planet and of the adjacent stars on twenty nights, according to a plan recommended by the Washington Observatory, and for which co-operation had been requested. At the request of Mr. Gill, the comparison stars which he needed for a determination of the solar parallax, by means of the planet Ariadne, have also been observed. An arrangement has been entered into with the United States Coast Survey for the determination of the position of all stars in the Northern Hemisphere visible to the naked eye, whose positions have not recently been determined with the greatest precision. Although the terms are not such as to be pecuniarily advantageous to the Observatory, yet the importance of the work, and the desire that our work may supply the wants of other scientific organizations, have justified our undertaking it.

Some work has been done, mainly on cloudy evenings, preparatory to the determination of the absolute positions of a standard catalogue of stars. A new method of determining the errors of graduation of the circles has been tried, and gives promising results.

Since the title of my professorship includes the term "Geodesy," it seemed desirable that this branch of science should not be neglected. Accordingly, last summer, by the aid of the Rumford Committee of the American Academy of Arts and Sciences, I undertook some observations on the atmospheric refraction in its relation to the determination of altitudes. By a new instrument, combining a high degree of accuracy with great rapidity, several thousand observations have been taken, and promise interesting results. The larger instrument, which weighs only about twenty pounds, gives results agreeing within a second of arc. With the smaller instrument, which is somewhat smaller than a surveyor's transit, nine hundred readings were obtained in a single day, the probable error of a single reading being less than five seconds of arc.

A good deal of miscellaneous work has also been done besides the above. At the request of Miss Mitchell, the difference of longitude of the Observatories of Vassar College and this Observatory was measured, and the result of our observations communicated to her. A similar determination of the longitude of the Observatory of the American Watch Factory at Waltham gave as a result $0^h\ 0^m\ 27^s.329 \pm 0^s.040$ west of Cambridge.

It may be taken for granted that any work is valuable which, by comparatively few observations, will increase the value of a previous much larger series of observations. Two memoirs offer a tempting field in this respect, — the observations of variable stars by Argelander, and the magnitudes of the stars given in the Durchmusterung. The first of these gives over thirty thousand determinations of the brightness of the most important variable stars, observed during thirty years by one of the most skilful of observers. But the results are only comparative, and at present almost valueless. A portion of these observations have been reduced by Mr. C. H. Metcalf, student at this Observatory; and it is proposed to measure the brightness of the comparison stars, and thus determine the true brightness of the variables, as given by this immense mass of observations. The Durchmusterung contains eye-estimates of the brightness of three hundred thousand stars, each observed twice. But we have no knowledge of the true brightness of the fainter magnitudes. It is proposed to measure the true value of this scale, so that the brightness of the fainter stars may be known in terms of the brighter.

TIME SERVICE.

One of the great benefits conferred on mankind by the science of astronomy is in providing an accurate standard of time. For many years this Observatory furnished the city of Boston gratuitously with the correct time, so that the bells of the fire alarm might be struck precisely at twelve o'clock. In 1872, Professor Winlock, appreciating the advantages of an extension of this system, succeeded, by his energy and enthusiasm, in interesting the public in the matter. Principally by the aid of the cities of Boston and Cambridge, and of the railroads centering in Boston, an income was obtained which justified placing the Time Service on a more permanent basis. The public generally do not appreciate the cost involved in obtaining the time with precision. Besides the current expenses, which are very large, the Observatory has invested about eight thousand dollars in instruments, clocks, telegraph lines, &c., used for this purpose alone. The city of Boston pays five hundred dollars annually for the time, — a sum less than one-half of that paid by other cities of similar size.

Last spring, as it was found that the receipts from the Time Service did not equal the expenditures, its discontinuance was seriously considered. This would have been done very reluctantly, since its value is appreciated; but the funds of the Observatory were intended by the donors to be applied to purely scientific work, and their application to other purposes does not seem legitimate. Active measures are now being taken to secure a wider knowledge of our time-signals, by circulars, letters, and personal interviews. The Western Union Telegraph Company have expressed a readiness to co-operate in the matter, and to offer favorable terms, in view of the scientific value of the work. It is hoped that a satisfactory arrangement may be made with them, both in view of the great facilities commanded by this company, and in acknowledgment of the interest they have hitherto shown by offering the use of their lines for the purposes of science.

An extension of our time-signals is desired in the following directions: 1st. The cities and towns. By striking a bell at noon or other convenient hour, by dropping a time-ball, or by controlling a public clock, the accurate time may be furnished to a very large number of persons. 2d. Railroads. The importance of accurate time in railroads is generally admitted, and, by preventing accidents, may make a great saving of life and property. 3d. Large manufacturing companies. The importance of accurate time in mills and factories employing several hundred operatives is not generally appreciated. Where it has been tried, the result is most satisfactory; and the saving of a few seconds a day, by having a reliable standard, amounts to a surprising sum in the wages of the operatives in the course of a year. If the time is irregular, an allowance must be made for difference in the clocks, which is avoided if all are kept to the same standard. 4th. Jewellers and clockmakers, to whom an accurate standard is of course indispensable. 5th. Private individuals might, in many cases, like to have an accurate standard, especially where they are dependent on the railroads for reaching their places of business.

Additional particulars relating to the Time Service will be found in Appendix C.

INSTRUMENTS.

The condition of the large telescope is by no means as bad as the Committee supposed at their last meeting. The best evidence of this is found in the results obtained, during the past autumn, from some of the most difficult objects known. The optical condition seems wholly unimpaired, and most of the defects are those in the original construction. Thus the circles, as stated in 1855 by Professor Bond (more than twenty years ago), are too finely divided, and are very difficult to read. Some simple means of setting the telescope on a star with ease would save much valuable time in the observations. A new micrometer, capable of measuring large intervals, is much to be desired. That now attached to the instrument was made thirty years ago, and has the radical defect of all micrometers made at that time, that the fixed wire cannot be made to bisect a star without changing its place upon the scale, unless the whole telescope is moved. The west equatorial has been put in order, and adapters have been constructed, so that the eyepieces of the large telescope may be used on it. It is very convenient to supplement the other telescope, and many objects may be observed with almost equal advantage in the smaller instrument. To save the time of the larger telescope, many of the preliminary observations with any new apparatus are made with this telescope. The large meridian circle remains in excellent condition. The old meridian circle has been put in order, and the shutters have been repaired. It is found useful for experimental purposes, thus avoiding interference with the larger circle. The Russian transit has been brought into use during the past year for the time observations. Its case has been mounted on rails, so that it may be removed and replaced without endangering the instrument. The Zöllner photometer has also been taken to pieces and cleaned. The difficulty previously experienced with the lamp has been remedied, by replacing the latter by a German student-lamp, and mounting the whole on a stand capable of turning around a vertical axis.

The telegraphic connections in the Observatory, by the frequent additions made to them, had become very complicated. Twelve wires were accordingly run from one end of the building to the other, and all connections are now made through them.

BUILDING AND GROUNDS.

By the liberality of the College authorities, the house attached to the Observatory, which had become very much out of repair, was put in excellent condition. By making several much needed alterations its convenience as a residence has been greatly increased.

No funds are provided for the repairs of the Observatory building or care of the grounds. A considerable expenditure is desirable in repainting portions of the interior of the Observatory, in carpeting some of the rooms, and in re-covering the furniture of the library and computing rooms. There is danger that, if the grounds are left uncared for, they will suffer serious detriment. Some improvements have been effected, especially in the immediate neighborhood of the house; but no portion of the expense incurred has been charged to the Observatory funds, as there was no surplus available for this purpose.

ASSISTANTS.

Four assistants are attached to the Observatory,— Professor Rogers, Mr. Searle, Mr. Waldo, and Mr. Upton. To Professor Rogers has been assigned the entire charge of the new meridian circle; and the large amount and excellent quality of the work of this instrument is due almost wholly to him. All the observations with this instrument are made by Professor Rogers; and he also superintends their reduction, and prepares them for publication. Last spring, in recognition of these services during seven years, he was appointed Assistant-Professor of Astronomy in the Observatory. Mr. Searle, besides assisting in the equatorial observations, and having charge of the meteorological observations, attends to most of the clerical work of the Observatory. This includes the accounts, official correspondence, distribution of the publications, entering and acknowledging the books received, and other similar work. The order and system now introduced in this department is mainly due to Mr. Searle. The Time Service during the past year has been in charge of Mr. Waldo, who is making every effort to secure for it a wider use. He also, during last summer, obtained one of the best series of measurements of the satellites of Mars which have yet been obtained. Mr. Upton has rendered valuable assistance in the equatorial observations and in reducing the work of the meridian circle. From this statement it appears that the title "assistant" by no means represents the duties attached to the position. The salaries, also, of the assistants are quite out of proportion to the character of work expected, and are only from one-half to two-thirds of those given elsewhere for similar services. They were originally based on the expectation that the assistants would simply aid in the work of the Director. Now, by the growth of the Observatory, observations are made every clear night, with several instruments simultaneously, and the responsibility must therefore be thrown on the assistants themselves.

FINANCIAL CONDITION.

It is with much hesitation that I approach this subject. The liberal action of the wealthy men of Boston and vicinity in former days makes it seem ungrateful to point out as forcibly as is my duty our present needs. Many friends, however, assure me that the interest and pride taken by the public in our Observatory will not suffer our real wants to go unsupplied. The last subscription raised for this Observatory was in 1868, and gave us the new meridian circle. This instrument has been in constant use since its completion, and both in the amount and quality of its work will compare favorably with that of any other similar instrument, either in this country or in Europe. Great as was its cost, however, the expense of keeping it in constant use, including reducing and publishing the results, amounts to the income of a fund nearly six times as great; and, since no provision was made for meeting this outlay, it has been borne by the funds of the Observatory.

Our available means were so far consumed in this work, that but little remained for keeping the large equatorial in active use. Accordingly, for some years past, but little work of a high order has been done with this superb instrument. Although, by the erection of still larger telescopes at Washington and Chicago, our Observatory has lost its former pre-eminence in this respect, yet the best work is not always done with the largest instruments. There is scarcely any purpose for which our telescope is not sufficiently powerful, and an endowment by which it could be kept constantly employed would more than compensate for its smaller size. Although our present income is insufficient to keep this telescope in active operation; besides meeting the other expenses of the Observatory, yet I deemed it advisable to show that want of means alone would prevent our obtaining a large amount of most valuable observations with this instrument. The results have been shown above; and I need only state, that I hope that the friends of the Observatory will not suffer our telescope again to remain idle.

This Observatory has one great advantage over almost all other similar institutions in the country, and its prestige is due to this as much as to any other cause. It has a sufficient endowment to meet its current expenses, and to do a certain amount of scientific work. Accordingly, any additional endowment might be applied directly to obtaining scientific results. In a new observatory, a large sum must be expended on the building, on instruments, and on the unattractive items of current expenses, wants which here are already provided. Moreover, for the same reason that, in a large mill, cloth may be woven far better and more cheaply than by hand, so in a well-endowed observatory researches may be undertaken and carried through successfully, which would prove quite beyond the reach of smaller institutions. To attain the greatest efficiency, a skilful observer should never be obliged to spend time on what could be done equally well by an assistant at a much lower salary. Since, therefore, our assistants are now competent and obliged to do work requiring education and experience, our first need is for a number of additional assistants at low salaries, to perform the routine work of the Observatory. Each observer would be competent to keep at least two such assistants employed, and the amount of work done by a proper division would then be nearly proportional to the number of persons employed. We could thus, at comparatively small expense, more than double the amount of work now obtained in the course of a year.

To bring the Observatory to the highest state of efficiency with its present equipment, about six thousand dollars a year would be required in addition to our present income. This should be expended somewhat as follows: three thousand dollars for five additional assistants; one thousand dollars for increasing the salaries of the assistants now attached to the Observatory; one thousand dollars for apparatus and books; one thousand dollars for publications. With this income, our instruments would be kept constantly in use, the observations would be reduced and published soon after they are made, and the high position this Observatory so long held as the centre of astronomical science in this country would be regained. There are so many unsupported observatories with excellent instruments or buildings, that it seems a pity that this country should not sustain at least one in which the endowment should be sufficient to maintain the highest possible activity.

It has been suggested that there are many persons who would be unwilling to contribute a large sum outright, but who might be ready to agree to contribute a smaller amount yearly for five or ten years. If the sum named above could thus be provided, it is believed that the results obtained would secure, at the end of that time, a more permanent endowment. The active interest which would thus be taken in the work of the Observatory would be an excellent incentive to maintain the highest degree of activity.

The Observatory during the past year has lost one of its former patronesses by the death of Miss Charlotte Harris. By her will, the Observatory has received the most acceptable donation of two thousand dollars, rendered doubly valuable since it is made without restrictions. The Observatory is also indebted to Mr. Robert Treat Paine for a valuable pocket chronometer which he has deposited here during the past year.

Respectfully submitted.

EDWARD C. PICKERING, *Director.*

APPENDIX A.

REPORT ON THE 15-INCH EQUATORIAL.

In laying out a course of work for this instrument, two principles are to be considered: First, to avoid a duplication of the work done elsewhere with other large telescopes; and, secondly, that the observations shall be of such a kind that they cannot be made equally well with a much smaller instrument. The principal classes of work fulfilling the last of these conditions are as follows: —

1. Descriptions or drawings of the appearance of the heavenly bodies. — A full share of this class of work has already been done at this Observatory. Moreover, in the present state of science, it has less value than in former years.
2. Zone observations. — Three volumes of the Annals have been devoted to measuring the position of the stars between 0° and 1° north. Dr. Peters is engaged in the determination of the stars near the ecliptic, with the large telescope at Clinton.
3. Asteroids. — The discovery of these bodies is the natural consequence of 2. The telescopes at Clinton and Ann Arbor are mainly employed in this work.
4. Micrometric measurements. — The great telescopes at Washington, Chicago, and Cincinnati, are used almost entirely for these observations.
5. Spectroscopy. — Efforts have been made to secure a large telescope for Princeton College for this work.
6. Photography. — The telescopes of Mr. Rutherford and Dr. Draper are largely used for photographic purposes.
7. Solar phenomena. — The telescope of the Allegheny Observatory is devoted to this work. With a sufficient number of observers, either of the other classes of observations may be carried on simultaneously with it.
8. Photometry. — This subject offers a field almost wholly unexplored with large telescopes, either in this country or abroad. It has, therefore, been selected as that to which the greater portion of the time of our telescope will be devoted.

The problem of astronomical photometry may be stated in its most general form, as follows: To determine the brightness of all the heavenly bodies, so that all may be compared with a single standard. The photometric measurements heretofore published have been made almost entirely upon the planets and brighter stars. Our knowledge of the light emitted by the satellites and fainter stars is confined to estimates by the eye, according to an arbitrary scale, which differs with each observer.

In attacking this problem, it was necessary to invent a suitable instrument, to have it constructed and attached to the telescope, and to learn its capacities and defects, before useful observations could be obtained. Early in August, a photometer was made by attaching to the eye-piece of the telescope a Nicol prism and double-image prism. By the last of these, two images of any object are formed; and, by turning the Nicol prism through an angle given by a graduated circle, the relative brightness of the images may be altered in any desired proportion. Accordingly, if turned towards a double star, the faint image of the bright component may always be reduced to equality with the bright image of the faint component. Various double stars were thus measured, and the satellites of Jupiter were compared with one another.

The important discovery of the satellites of Mars by Professor Hall offered a problem of unusual difficulty for our new photometer. A telegram announcing the discovery was received on the morning of August 18, and the outer satellite was seen the same evening independently by Messrs. Searle, Upton, and myself. Each estimated and recorded the position and distance of the minute object we thought we saw; and a comparison of the results showed a close agreement. For some weeks after, the observations of these satellites were made the main work of the telescope. As simply seeing, without measuring them, was a matter of little scientific value, efforts were made to determine their brightness and position. Their extreme faintness rendered this a matter of no small difficulty. When Mars was in the field, the satellites could not be seen; while, when Mars was covered, its position, being unknown, prevented a measurement. The device was accordingly tried of inserting a small piece of colored glass in the field, through which Mars was seen. Its light was thus so far reduced as not to obscure the satellite; while the glass, being placed between the eye and the micrometer wires, occasioned no error in the measurement. By this method, a series of three hundred and twenty-two measurements were obtained by Mr. Waldo on fifteen different nights, as shown in the table given below. This series is believed to be surpassed only by the series taken by Professor Hall, at Washington, where the large size of the telescope used (giving over three times the light of our instrument) greatly facilitated the observations. The difficulty was increased by the fact that, as the telescope was used for photometric measurements of the satellites during the first part of the evening, almost all of the above measurements were made during the early morning hours.

The first attempt to measure the light of the satellites was made on August 27, by allowing Mars to shine through a very small hole placed in the focus of the telescope, and comparing this with the satellite. To obtain a hole sufficiently minute and circular was a matter of no small difficulty. My thanks are due to Messrs. Alvan Clark & Sons, Buff & Berger, Grant, Berry, and Van Woerd, for their efforts to make suitable holes for me. The last-named gentleman, Superintendent of the American Watch Company, at length completely solved the problem by the construction of a hole one eighteen-hundredth of an inch in diameter, and so nearly circular that the various diameters, including errors of measurement, only differed one hundred-thousandth of an inch! Even this hole, however, represented a satellite seventy miles in diameter, and shone out as a bright star when Mars was placed behind it. One hundred and eleven comparisons of this and other holes with the satellite were obtained, as described above. But the loss of light by the polarizing prisms rendered it a matter of extreme difficulty to see the satellite with the photometer on, even when it was easily visible with a common eye-piece. Moreover, it was very desirable to obtain measures by several different methods, and thus avoid any error due to the particular instrument employed. Personal errors were similarly eliminated by several observers repeating the measurement. A wholly different photometer was next tried. A small auxiliary telescope was attached to the large instrument, and by means of prisms the light of Mars was reflected so that its image formed by the little telescope should be seen by the side of the image of the satellite formed by the large telescope. The satellite seen with fifteen-inches aperture was still fainter than Mars, seen with a telescope having an aperture of less than a quarter of an inch. It was now easy to reduce the light of the small telescope with two Nicol prisms, so that Mars should appear no brighter than its satellite. The criticism might be made that Mars was seen on a dark background, while a field around the satellite was bright from the light of Mars. An artificial light was accordingly thrown into the small telescope, so that both backgrounds should be equally bright. But now the lamp-light was too red. Interposing blue glass rendered it too blue, but, partially removing the glass, an almost perfect match of the two backgrounds was obtained. We then had two stars on fields which were first rendered equally bright, then matched in color, and the image of Mars was then brought to precisely the same brightness as the satellite. Two hundred and eighty-two comparisons of the outer, and seventy-two of the inner, satellite were thus made. It was noticed under these favorable opportunities for comparison that the outer satellite did not partake of the red color of Mars: a curious result, and having an important value in any theory of the cause of the peculiar color of Mars.

To compare the two satellites directly with one another, still a different method was tried. One, two, and three plates of thin glass were successively interposed between the eye and the inner satellite. Its light was thus so far reduced as to render it equal to, or fainter than, the outer and smaller satellite.

These observations have not yet been wholly reduced: it is therefore impossible to give the final conclusion. The best idea of the light of a satellite is obtained by giving the diameter to which the primary must be reduced to render it no brighter than the satellite, or the diameter of the latter, if it reflected light in the same proportion as the planet. This is, in fact, probably the only estimate we can ever make of the true diameter of these bodies. An approximate reduction of the measurements of the outer satellite, comparing its light with that from the holes, gives its equivalent diameter at about 5.9 miles. The result of the other comparison is about 5.4 miles. This agreement is all that could be desired. The observations of the inner satellite give its diameter as 6.5 miles. The direct comparison of the two gives their relative diameters as in the ratio of 10 to 9. These figures will be somewhat altered in the final reduction. As the darker color of the outer satellite somewhat diminishes its light, it is probably safe to call it about six miles in diameter, and the inner satellite seven miles. The labor involved in these measurements was very great, especially since, the instruments being new, it was often necessary, after spending a large part of the night on the observation, to devote a considerable portion of the day to alteration or tests of the instruments, or measurements of the constants involved. Space does not permit a description of the various methods employed for measuring these constants, especially that showing how far the light of Mars was reduced by the small telescope. It is only necessary to say that several independent methods were employed, and several observers. The number of photometric and micrometric measurements obtained each evening are given in the annexed table: —

Observations of the Satellites of Mars.

Date.	Photom. Obs.		Micrometric Measurements.			
	Outer.	Inner.	Pos. O.	Dist. O.	Pos. I.	Dist. I.
August 27th.	35					
,, 28th.	40		5	5		
,, 29th.			7	7		
,, 30th.	16		19	19		
September 2d.			5	5		
,, 6th.	60		7	7	15	15
,, 8th.	80	20				
,, 9th.			9	8	5	3
,, 11th.		12				
,, 12th.	42	10				
,, 13th.	60	20	1			
,, 14th.			22	22	22	22
,, 16th.	40	10	12	12	3	3
,, 18th.			5	4		
,, 23d.	20		12	2	6	
,, 25th.			10		1	
,, 26th.			10			
,, 30th.			11	11		
October 12th.	6					
19	399	72	135	92	52	63

The last of these measurements was made by still another method. So much difficulty was experienced in the attempt to obtain Nicol prisms with flat surfaces, that this method of reducing the light was discarded, and the aperture of the small telescope was reduced by covering the objective with two V-shaped plates, which could be brought together by means of a screw. This photometer has since been used upon various other objects. A large number of measurements of seven of the satellites of Saturn have been obtained, including the very faint object Hyperion, whose light is thus determined with great precision. Numerous other very faint objects have been similarly measured, especially some minute companions to bright stars. Standards will thus be established for the fainter stars, with which observers hereafter can compare other minute objects. Several asteroids have been compared in like manner, and will give some reliable data regarding the true diameters of these bodies.

Of the miscellaneous work done with the large telescope, the most important has been the observation of several asteroids. On the evening of October 27, by means of an ephemeris derived by Professor Rogers from new elements also computed by him, Mr. Upton found Brunhild (123), which had eluded the search of astronomers at the last opposition. Observations were also obtained of Diana (78), at the request of M. Doubiago, of the Pulkova Observatory. Mr. Searle and Mr. Upton have assisted in all the above photometric observations, and by their skill and perseverance have contributed largely to their success.

EDWARD C. PICKERING.

APPENDIX B.

REPORT OF THE WORK DONE WITH THE MERIDIAN CIRCLE BETWEEN NOV. 1, 1876, AND NOV. 1, 1877.

Professor Edward C. Pickering,
Director Harvard College Observatory:

Dear Sir, — The present report covers the period from the date of the last report made to the Committee of the Board of Overseers in November, 1876, to November 1 of the current year. Observations have been made on 147 different nights, the distribution according to the months of the year being as follows: —

Month.		No. of nights in which Observations were made.	Month.		No. of nights in which Observations were made.
1876.	Nov.	18	1877.	May	6
„	Dec.	10	„	June	15
1877.	Jan.	7	„	July	18
„	Feb.	12	„	Aug.	21
„	March	14	„	Sept.	10
„	April	12	„	Oct.	9

The observations made, form for the most part a continuation of the series, which has been in progress, with little interruption, since November, 1870. During the present Summer and Fall, however, Mars has been observed on twenty different nights, together with the comparison stars selected by Professor Eastman, of the Washington Observatory.

At the request of Mr. Gill, of Aberdeen, who has undertaken observations of the minor planet Ariadne, and of Mars, with reference to a new determination of the solar parallax, six observations of each star of the list of comparison stars furnished by him have been made.

The whole number of observations made during the year is 5285, distributed as follows: —

Zone stars	2700
Fundamental stars	2200
Ariadne comparison stars	72
Mars comparison stars	152
Mars, with stars of Eastman's list . . .	161

The following brief *résumé* will indicate the various classes of observations made with the meridian circle, since it was mounted in 1870:—

From Nov. 10, 1870, *till April* 25, 1871.

The zone observations between the limits, + 49° 50′ and + 55° 10′, undertaken under the auspices of the Astronomische Gesellschaft, were begun Nov. 10, 1870. From this date till March 28, 1871, the observations were made on alternate nights by myself, with Mr. Augustus McConnell as reader of the circle, and by Mr. E. P. Austin, with Mr. Arthur Searle as circle-reader.

Previous to April 25, 1871, only the fundamental stars selected from the Gesellschaft list of 529 stars were observed in connection with the observations of zone stars.

From April 26, 1871, *to May* 22, 1872.

The demand of the United States Coast Survey for a more extended list of time stars, in connection with its longitude determinations, induced Professor Winlock to undertake a re-observation of the general catalogue observed in right ascension only with the old transit instrument, during the years 1867 and 1868. The working list of this catalogue was so constructed that the primary stars required to reduce the secondary stars should at the same time serve the same purpose for the zone observations. Of the 564 stars composing the whole list, 289 were selected from the list of 529 stars mentioned above.

The completed series contains 3900 observations.

From June 11, 1872, *to Dec.* 31, 1873.

Upon the termination of the observations of the general catalogue, Professor Winlock determined to enter upon the observation of a polar catalogue, with the view of furnishing the positions of a larger number of stars suitable for the determination of instrumental constants than were at that time available. The working list was, as far as possible, so constructed that the interval between successive transits of polar stars should not much exceed ten minutes of time. 148 of the stars of this list are situated beyond 60° north declination.

The primary stars were selected from the list of 529 stars with reference to their serving the double purpose of being suitable for the reduction both of the polar stars and of the zone observations, which were, as in 1871 and 1872, carried on in connection with them.

The completed series contains 3900 observations.

From Jan. 1, 1874, *to Dec.* 31, 1875.

It was Professor Winlock's first intention to delay the re-observation of the general catalogue of 1871–72 till about 1880; but the small systematic deviation of the right ascensions of stars having large south declinations, from the values given by the Greenwich and the Washington observations, as shown by the preliminary reductions, induced him to reconsider this purpose. The re-observation, therefore, was begun in January, 1874, and was completed in December, 1875. As far as possible, an equal number of observations of each star was made with the instrument in opposite positions.

The completed series contains about 6500 observations.

From Jan. 1, 1876, *to Dec.* 31, 1877.

The two special series of observations undertaken by Professor Winlock having been completed, a new working list of fundamental stars required for the reduction of the zone observations was selected for the years 1876 and 1877. The first requirement of the selection was that the selected stars should be as near the region of + 50°—+ 55° declination as possible. To this list were added stars of the following classes: —

(*a*) The stars of Bessel's Catalogue for 1820. [Königsberg Observations for 1819–20, p. xv.]

(*b*) All the brighter stars of Struve's Catalogue for 1815. [Obs. Astron., F. G. W. Struve, Pars II. p. 65].

Nearly all the stars of lists (*a*) and (*b*) are common to the list of 529 stars.

(*c*) A short list of fundamental stars, situated near the equator and as far as possible equally distributed over each hour of right ascension.

It has, for the most part, hitherto been the custom to determine the constant difference between different systems of observed right ascensions, by taking the mean difference between all the right ascensions observed, without regard to the position in declination. This is open to the objection that the result is, to a certain extent, affected by the systematic errors depending on the declination alone. This constant difference is generally regarded as a difference in equinox. The object, therefore, of including the list of stars situated on or near the same parallel of declination is to furnish data for a more accurate determination of the constant differences existing between various catalogues.

(*d*) A short list of secondary stars furnished by Professor T. H. Safford, as needing farther observations.

(*e*) A short list of extreme south stars.

The working list of primary stars is arranged for six observations of each star in each position of the instrument, the circle being west during 1876 and east during 1877.

The thirty-two bright stars, known as the "Maskelyne Fundamental Stars," were observed as often as opportunity occurred; and throughout the year 1876 they were observed during the morning hours as well. We have therefore the data for a partially absolute determination of the stars common to the Gesellschaft list.

A few changes were made in the methods of observation at the commencement of this series.

(*a*) A new system of wires was inserted at the focus of the two collimators, adapted to the double purpose of measuring the collimation and the flexure, the system of wires furnished with the instrument being unsuited to the determination of the latter constant.

(*b*) Previous to this date, the diurnal aberration was applied to the mean of the observed right-ascension wires. From this time it is elimnated from the setting of the system of transit wires for the zero of collimation.

(*c*) Between 1870 and 1874, only two microscopes were read for each setting of the instrument. During 1874 and 1875, two microscopes only were read; but two settings of the circle were made, giving two independent determinations of the declination, the first reading being by Mr. Joseph F. McCormack, and the second by myself. From January, 1876, four microscopes have been read, and for the most part two independent settings of the instrument have been made.

(*d*) Since September, 1876, six independent observations in declination have been made at each observed transit of the four close polar stars, α Ursæ Minoris, 51 H. Cephei, δ Ursæ Minoris, and λ Ursæ Minoris. These observations are intended to furnish the data for accurate determinations of the equator-point corrections of the circles.

(*e*) In August of the present year, the object-glasses of the collimators were adjusted for the line of the optical axis of the telescope. Since this was done, the images of the wires in the collimators, as seen through the telescope, have been much improved. At this time a compound microscope was first used in connection with the collimators, instead of simple eye-pieces, as previously. As a consequence, the collimation has since this time been determined with a somewhat greater degree of precision than before.

The zone observations have been continued with but little interruption since November, 1870. The following table will indicate the number of stars to be observed in each degree of declination, and also the number of observations which have been already made: —

Zones.	No. of Stars to be observed.	No. of Observations which have been made.
From + 49° 50′ to + 51°	1956	4820
+ 51 to + 52	1608	3762
+ 52 to + 53	1561	3418
+ 53 to + 54	1488	2866
+ 54 to + 55 10′ *	1709	3156

The following table will indicate the number of observations yet remaining to be made. Quite a large number of these stars have been observed once; but they are nevertheless included, since, by the plan of observation followed from the first, two complete consecutive observations of each star are required before it is checked off from the working list.

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* The stars on the outside limits are distributed equally over zones + 50° and + 55°, no separate count having been made.

Hour of R. A.	+49° +55°	+50°	+51°	+52°	+53°	+54°	Sums.
0 . . . 1	1	19	25	50	61	76	232
1 2	0	13	44	71	58	82	268
2 3	0	9	8	26	43	41	127
3 4	0	21	19	24	32	22	118
4 5	0	6	7	12	24	18	67
5 6	0	3	1	2	22	13	41
6 7	0	2	0	2	2	4	10
7 8	0	2	4	4	1	2	13
8 9	0	0	0	0	8	3	11
9 10	0	0	1	0	0	1	2
10 11	0	2	1	1	1	4	9
11 12	6	1	4	1	2	3	17
12 13	7	1	1	1	4	0	14
13 14	2	4	4	3	7	7	27
14 15	1	2	3	0	3	2	11
15 16	3	1	1	2	0	0	7
16 17	4	0	3	0	1	1	9
17 18	4	0	1	1	1	4	11
18 19	4	0	1	2	1	7	15
19 20	1	6	5	2	2	1	17
20 21	7	13	8	13	6	6	53
21 22	2	0	5	5	2	3	17
22 23	4	11	7	17	23	14	76
23 24	11	11	44	29	31	48	174
Sums	57	127	197	268	335	362	1346

Since each star requires at least two observations, about 2700 complete observations must be made in order to complete the series. If the weather is moderately favorable during the months of November and December, of the present and the following year, it may be assumed that the zone observations will be completed by the end of 1878.

The following table gives the total number of observations of the various classes, made since the instrument was mounted in 1870:—

Résumé.

Zone observations	18000
Fundamental stars between Nov. 10, 1870, and April 26, 1871	800
Time determinations for longitude, &c.	1000
Asteroid comparison stars, &c.	1100
General catalogue, 1871–72	3900
Polar catalogue, 1872–73	3900
General catalogue, 1874–75	6500
Fundamental stars, &c., 1876–77	4400
Observations by Messrs. Austin and Searle . . .	1000
Total	40600

Description of Records.

For a detailed description of the various classes of books in which the observations are recorded, reference is made to the accompanying exhibit, marked "Exhibit I."* The following rule has been adopted in designating the different classes of records: —

Each record-book has a distinctive title-page, on which its contents are described. Whenever there are several books of the same class for any given year, they are marked as follows: —

Original records, or records made in note-books, at the time the observations are made, such as circle-readings, barometer, thermometer, runs, &c., are designated A_1, A_2, A_3, according to the number of books required for each year. Thus the title-page for the fundamental stars observed during the latter half of 1877, reads, —

Zone Fundamental Stars.
Circle Readings.
From $20^{h} 13^{m}$ to $23^{h} 58^{m}$.
1877, A_2.

Books containing copies of the original observations, together with the various reductions required, are marked B_1, B_2, &c.; but since the zone observations constitute a distinctive class, the reduction books are lettered C_1, C_2, &c.

State of the Reductions. Zone Observations.

As it was found impossible to keep up the reductions during the continuance of the zone observations, without the employment of a larger force of computers than the funds of the Observatory would at that time allow, Professor Winlock directed that certain parts of the work should be done in the following order of preference: —

I. Reading of the chronograph sheets, and copying both the threads and the circle-readings in permanent form.

II. Preparation of sheets for publication, containing every thing necessary for the final reductions. These sheets are made up as follows: —

  (*a*) The separate wires in right ascension.
  (*b*) The time of transit over the mean of the wires.
  (*c*) The time of transit over the mean of the declination wires.
  (*d*) The circle-readings.
  (*e*) The mean of the circle-readings.
  (*f*) The circle-readings reduced to the fictitious horizontal wire.

III. (*a*) Taking the means of the right-ascension wires, the declination wires, and of the circle-readings, both in the books and on the sheets, and also the argument for the reduction of the circle-readings to the horizontal wire; viz., the time of transit over the mean of the right-ascension wires minus the time of transit over the mean of the declination wires.

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* Not printed with this Report.

(*b*) Comparison of the resulting means, and an examination of all discrepancies.

IV. The computation of the clock errors and the instrumental constants for the various catalogues observed; the final reductions of the fundamental stars for the zone observations being deferred till the arrival of the Pulkova positions.

In accordance with this plan, the following work has been done: —

The chronograph sheets have been read to November, 1877, and the results, together with the circle-readings, have been copied into the zone-record books, C_1 to C_{40} inclusive. The records in the zone books have been copied on sheets, No. 1 to No. 396, as far as Nov. 1, 1875. The means have been taken both in the books and on the sheets as far as June 10, 1874. They have been checked by comparison as far as April, 1874. In all doubtful cases, the original chronograph sheets have been examined. Following Professor Winlock's plan, these sheets, therefore, are ready for printing, except filling out the column, "Reduction to horizontal wire."

General Catalogue, 1871–72.

The observations and reductions, together with the discussion of the results, constitute Volume X. of the Annals of the Observatory, published in March of the present year.

Polar Catalogue, 1872–73.

Since not more than ten days are required to complete the reduction of the observations constituting this catalogue, the work is practically ready for printing. The formation of the final catalogue positions and the discussion of the results yet remain to be done.

General Catalogue, 1874–75.

(*a*) The sheets are all read off, and the results, together with the circle-readings, have been copied in permanent form.

(*b*) The means of the right-ascension wires, the declination wires, and of the circle-readings have been taken in duplicate, and all discrepancies have been examined and corrected.

(*c*) The reductions to apparent place have been completed, and they have been checked by an independent computation of the reduction for the first date for each star.

(*d*) The reduction of the circle-readings to the fictitious horizontal wire is nearly completed.

(*e*) All the general constants required in the reduction of the observations have been computed.

Fundamental Stars, 1876–77.

The chronograph sheets have all been read, and the results, together with the circle-readings, have been copied in permanent form.

About one-half of the means have been taken, and the general constants for the whole series have been computed.

Refraction Constants.

As explained in Vol. X. p. xx, the variable part of the refraction consists of the term $[B + T + \gamma]$, and a small term $[\lambda\gamma - \gamma]$, which is taken from manuscript tables. The greater part of the refraction, therefore, is found by adding $[B + T + \gamma]$ to the term $[\mu + \text{tang } z]$, which is taken from the Pulkova tables. This term $[B + T + \gamma]$ has been computed from November, 1870, to November, 1877.

Respectfully submitted.

WILLIAM A. ROGERS.

Harvard College Observatory, Nov. 1, 1877.

APPENDIX C.

Professor **Edward C. Pickering**,
Director of the Observatory of Harvard College:

Dear Sir, — In accordance with your request, I submit the following report relating to the Observatory Time Service, since its general care was assigned to me as one of my duties, Feb. 10, 1877.

At that date, the details of the service, under the supervision of Assistant-Professor W. A. Rogers, were as follows: —

The determination of clock errors was made with the meridian circle, using the stars of the American Ephemeris.

The clock Frodsham 1327 was used in the observations, which were all recorded upon the chronograph.

The daily error of the standard mean-time clock, as determined from comparison with Frodsham 1327, was kept within a fraction of a second, as nearly as practicable; and at 10 A.M. its amount was telegraphed throughout the telegraphic circuits immediately controlled by the Observatory. The clock was mounted in the Prime Vertical Room, and distributed its beats each two seconds throughout the twenty-four hours, omitting the 58th second of each minute, and from the 34th to the 60th second of each five minutes. The accumulative error was destroyed by adding to or taking from the pendulum small weights. The signals were transmitted to the Western Union Telegraph Company, to the offices of six of the leading railroads terminating in Boston, and to ten of the leading jewellers' firms. The indirect distribution of the time signals over the lines of the railroads and of the Telegraph Company made it a virtual standard of time in many of the New England cities.

The private lines of the Observatory were under the care of Stearns & George, telegraph constructors, who have always discharged this duty to the satisfaction of the Observatory, and who received therefor a compensation based upon the actual material and labor consumed during the year.

The telegraph lines under their care, and owned by the Observatory, were divided into three circuits, each with its respective battery, known as the Main Circuit, which included the Observatory, the Fire Department of the City of Boston, the place of business of William Bond & Sons (where was placed the alternative Boston clock), and the office of Stearns & George, at 32 Pearl Street. In this office the batteries and telegraphic apparatus generally of the service were stored. Here also were placed the distributing relays, which worked two other telegraphic circuits. One, known as the Southern Circuit, extended to the Old Colony Railroad Depot in South Boston; the other, known as the Northerly Circuit, included the depots on the other side of the city. The Observatory was also in direct communication with the Western Union Telegraph Office in Boston, through an independent wire, which went *via* Allston and the Boston and Albany Railroad.

The Western Union Office was connected by a special line with the place of business of William Bond & Sons.

It had been found necessary to have a clock in Boston kept with the time signals, in order to obviate an interruption to the time signals in the case of the interruption of telegraphic communication between Boston and Cambridge.

It became only necessary in this latter case to transmit the signals from William Bond & Sons to Stearns & George, who in turn distributed them through the relays, commonly worked from Cambridge, until such time as the Cambridge line could be restored.

Through the efforts of the late Professor Winlock and of Professor Rogers the service had been maintained for five years. In that time the community generally had been unconsciously educated to the desirability of a uniform standard of time. Accurate time-pieces, in many places, were daily compared with the Observatory signals, and their rates so determined were considered authoritative. So critical, indeed, had the subscribers become, that errors of a fraction of a second were detected and commented upon. It had become, indeed, a question as to how much farther the Observatory would be justified in perfecting its system, since it had already expended several thousand dollars in bringing the system to its present state of accuracy, and the funds properly applicable to such a purpose were exhausted.

After some deliberation, aided by public sentiment in the matter, it was decided to place the Time Service in a position to furnish the time signals with the utmost attainable precision, and then to request the co-operation of the Western Union Telegraph Company in transmitting these signals over the whole area of New England, as it was believed that the New England cities interested would combine to render the service self-supporting. To carry out this policy, it was decided to protect the clocks at the Observatory used in transmitting the signals from climatic variations; to systematize the telegraphic connections throughout the Observatory circuits; and to make the determination of the clock error the special duty of one observer.

Under these three heads it may be well to describe the service as at present organized.

THE CLOCKS AND CLOCK-ROOM.

The new clock-room in the west-wing cellar of the Observatory was completed by Mr. Stevens, March 2, 1877.

It is a rectangular wooden structure $3^{m}.04$ (10^{ft}) long by $1^{m}.27$ ($4^{ft}\ 2^{in}$) wide, and $2^{m}.7$ ($9^{ft}\ 10^{in}$) high outside measure. It has double walls, with a space of $0^{m}.135$ between them. Its roof is of the same thickness. The direction of the rectangle is north and south. On its eastern side are two doors; one of them is bevelled and flanged like a safe-door, and is built as thick as the walls. This door closes against felt-packing, so that it shuts very snugly. Outside of this door is the other, larger, closing over it in such a way that the edges of the first door are covered by a felt-lining to the outer one. On the side opposite the doors three square apertures were cut, each one opposite the face of a clock occupying one of the three piers erected within the clock-room. These apertures are closed by window-sashes, containing a single pane 30 cm. square. Two such sashes are used for each aperture; one is set into the outside wall and the other into the inside wall of the clock-room, so that there is an air-space between them equal to the thickness of the walls. Tin reflectors throw the light from a distant window through the sashes, to illuminate the clock-faces within the room.

The piers differ for each clock in material and design. The southernmost pier is composed of two brick columns supporting a marble slab, which supports the standard mean-time clock.

The middle pier is of sandstone, and supports the sidereal clock, Bond 312.

The northernmost pier is of granite, and is designed for the reception of an alternative mean-time clock, to be used in case of stoppage of Bond 394.

The standard mean-time clock, Bond 394, is a beautiful specimen of horological workmanship; it was built in 1867, and was exhibited at the Paris Exposition, where it received a high recognition. The escapement is a form of the gravity escapement, invented by Richard F. Bond. The pendulum consists of a single steel jar filled with mercury, attached to a single steel pendulum-rod, which is suspended by a flat spring from the back of the clock movement.

The dimensions are as follows: —

Length of jar, outside, 23.6 cm. ($9^{\text{in}}.3$).
Diameter of jar, outside, 6.3 cm. ($2^{\text{in}}.5$). Inside, 5.8 cm. ($2^{\text{in}}.3$).
Depth of mercury inside, 18.2 cm. ($7^{\text{in}}.20$).
Length of pendulum-rod 84.4 cm. ($33^{\text{in}}.25$). Diameter 0.5 cm. ($0^{\text{in}}.20$).

The break circuit arrangement is in the movement itself, differing from the usual pattern in which a point on the pendulum makes a contact with a globule of mercury.

It is a companion clock to the famous mean-time clock of the same makers in the Liverpool Observatory. This latter clock has had two modifications in its movement. The spring by which the pendulum is suspended has been made 2.5 cm. wide at the top; it is wedge-shaped, made of untempered steel, and was ground under oil, to avoid heating the spring in making it. This Mr. Hartnup considers an important matter in the support of the pendulum.

The second modification grew out of a difficulty which we have experienced here, — a liability of the clock to stop, from the escape-wheels not exactly gearing after one of them has been at rest the fraction of a second preceding the unlocking of the escapement by the pendulum. These wheels in the Liverpool clock have been doubled in diameter, and instead of teeth the wheels gear into each other by the friction of their vulcanite rims.

The performance of this clock is so remarkable, that the following monthly means of its daily rates, during the summer of 1876, are worthy of notice: —

Mean Daily Rates of Clock, Bond 395.

1876.	Uncorrected for Barometric Pressure.	Corrected for Barometric Pressure.	Mean Height of Barometer.
	s.	s.	in.
March	+ 0.03	+ 0.06	30.16
April	+ 0.04	+ 0.05	30.04
May	+ 0.05	+ 0.07	29.96
June	+ 0.11	+ 0.08	29.86
July	+ 0.09	+ 0.08	29.97

And in comparison with this it might be stated that between the dates of March 8, 1872, and July 22, 1872, the difference between the greatest and least rates of Bond 394 was $0^s.4$, although exposed to a variation of temperature of 60° F. That our own clock, Bond 394, has not shown so small variations in its rate as in the above table is in some measure owing to the fact that its error is made zero whenever it is determined, a disturbance which naturally would affect its rate.

This is necessary because of the different hours at which the time signals are distributed by the subscribers. The railroads generally distribute the signals in the morning and evening along their lines. The Western Union Telegraph Company switch the signals into any of their circuits when it is called for.

In order to keep the clock always right, it became necessary to introduce some ready means of correcting its error at any time. It was determined, by experiment, that the addition of one gramme to the top of the pendulum-bob caused the clock to gain $0^s.027$ in one hour; and for several months the clock error was daily corrected by altering the number of grammes on its pendulum for a definite time. Although the weights were handled with forceps with the utmost care, it was found almost impossible to alter them without disturbing the half arc of vibration at least one minute of arc, which would cause a change of $0^s.12$ per day in its rate, according to the experience of the Berlin Time Service. It was determined, therefore, to alter the clock error by the principle suggested by the present astronomer-royal, Sir George B. Airy, which consists in retarding or accelerating the motion of the pendulum by means of reversed currents acting on the same pole of a magnet.

Accordingly a bar-magnet 7 cm. ($2^{in}.8$) in length is attached to the pendulum-rod at a distance of 21.6 cm. ($8^{in}.5$) above the top of its bob. When the pendulum is vertical, one pole of this magnet is within 0.25 cm. ($0^{in}.1$) of the top of a small helix of copper wire wound about a soft iron core. At any time a positive or a negative current may be passed through the helix, and with a battery of three gravity two-quart cells the clock error is affected $0^s.05$ in sixty seconds. This device has been found extremely convenient in practice, since by merely changing two switches the clock error may be altered any desirable amount; and it is not necessary to open the clock-room to effect this change. The wires from the clock connections terminate in screw-cups on the outside of the clock-room. It is only necessary, therefore, to open the room when the clocks need winding.

The clocks had not been many weeks in their new position until a difficulty presented itself, which seriously threatened the abandonment of the room altogether. It was designed from the first to dry the air of the room by means of pans of calcic chloride; but it was found that the percentage of moisture was only slightly diminished by doubling the quantity of the chemical, though in each case the chemical was saturated at the end of the same length of time.

This led to the inference that the supply of moisture was practically unlimited, and that it would be received from the damp concrete floor as rapidly as the chemical would absorb it from the air. In order to avoid any tremor, a space between the piers and the floor, about one half of an inch, had been filled with sand: this, doubtless, was an additional inlet for the moisture. After removing the clocks twice from the room, it was decided finally to put a floor of sheet-lead under the clock-room. This has been done, and the juncture of the leaden floor with the piers and with the walls of the clock-room has been set with a glazed cement. It is now possible to control the moisture so that there is 25% less than in its old position in the Prime Vertical Room. The temperature of the room is extremely equable.

The effort to establish clocks in basements of buildings has given rise to many fruitless and costly experiments; but, singularly enough, very few of these experiments have been described in print, and during an inspection of the time services in Europe, the writer found it to be generally believed that the only way to put a clock in the basement would be to put it in a hermetically sealed case, as is done, for instance, at Berlin, — the theory being that the conduction of heat through the pier into the ground would keep the temperature of the pier and of the clock below the temperature of the surrounding air, and hence condense moisture on the exposed surfaces. But the writer thinks it is questionable whether the conduction of heat through the piers is rapid enough to make any sensible difference between the temperature of the air and of the pier in clock-rooms, constructed as in the present case.

THE TELEGRAPHIC CONNECTIONS.

The clocks in the clock-room work combination relays, placed on a shelf outside of the room; but it is only with the single relay worked by the mean-time clock that we are concerned.

This relay receives three additional circuits. Two lines are grounded through it, and are led with the Observatory system of wires to the East Transit Room, where they terminate in switches so arranged that one of the lines may be connected with a relay in the Western Union Telegraph Company's circuit, and the other with a relay in the Observatory main circuit. The third controls a clock on the Jones plan in the computing room. This is the arrangement when the Cambridge clock is sending the signals.

When the Boston clock is sending the signals, or when it is desired to communicate with Boston, as at 10 A.M., for instance, the two circuits become ordinary telegraph lines grounded at the Observatory and at the two offices named in Boston, by simply moving the switches.

The two relays in the East Transit Room are connected by a telegraph line passing through speaking instruments at the residence of the Director and the writer's house on Madison Street. Any interruption of the signals thus becomes apparent at these two places.

The city circuits remain as they were, with the exception that the Western Union Telegraph line has been prolonged to the office of Stearns & George, so that at this latter office the signals are received over the two lines at the same time.

For communication with our city agents, a telephone has been placed in the Observatory, and one each at Bond & Sons, 97 Water Street, and at the office of Stearns & George, 32 Pearl Street.

THE DETERMINATION OF CLOCK ERRORS.

The sidereal clock, Frodsham 1327, continues to be the clock to which all observations are referred. It is situated a few feet from the sounding relays in the East Transit Room, and is thus easily compared with the mean-time standard. The "Russian Transit," described in Vol. VIII. of the Annals, is used for the observations. It has an aperture of 6 cm. ($2^{\text{in}}.75$), and stars of the second magnitude may be observed with it in the daytime. The constancy of its collimation error is all that could be asked; but the variation of its azimuth and level errors would probably be lessened by supporting the instrument upon a solid pier, instead of the marble slabs at present used.

The observing list is the list of 539 stars issued by the "Astronomische Gesellschaft." The observations are made of stars for position and time, with the circle in each position.

The sidereal break-circuit chronometer, Frodsham 3451, is used in the observations; and experience has shown that the chronographic method in this particular case consumes more time, without a corresponding increase of accuracy, than the eye and ear method, which, accordingly, is adopted.

The determination of clock errors occupies from two to three hours each observing night, and observations are made each day the weather permits. The final clock correction at present is determined by giving equal weight to the sidereal and to the mean-time standards. In distributing the time signals, the Observatory has found it necessary to erect some eleven miles of private lines. These lines employ about fifty cells of gravity battery, and work through twenty sounders and fourteen relays.

The Western Union Telegraph Company control a clock in their building by means of the two-second current received from the Observatory. As regards the accuracy with which the signals are transmitted, the error from cloudy weather may reach $0^{\text{s}}.4$, in extreme cases. But, ordinarily, the clock-beats are correct within $0^{\text{s}}.15$.

The signals are all referred to the meridian passing through the State House, Boston, which is assumed to be $15^{\text{s}}.50$ east of Harvard College Observatory.

It has been found that in cases where the time is given by large bells, as in the case of the Boston Fire Department, the error is much larger than that given above, and is apt to vary from day to day, owing to the variation in the time required for the mechanism used in striking the bell to act. It is difficult to give criteria by which to judge of the excellence of a given system. The writer selects two cases, taken at random from the note-books of two of the best time services in Europe, — at Berlin and Liverpool, neither of which reduce the accumulated error daily.

Error of Daily Time Signals at Berlin.

			s.				s.
1877.	June	1		1877.	June	8	+ 0.1
,,	,,	2		,,	,,	9	— 0.1
,,	,,	3	+ 0.2	,,	,,	10	— 0.1
,,	,,	4	— 0.2	,,	,,	11	— 0.2
,,	,,	5	— 0.8	,,	,,	12	— 0.4
,,	,,	6	— 0.5	,,	,,	13	— 0.1
,,	,,	7	— 0.3	,,	,,	14	+ 0.4

Error of Daily Time Signals at Liverpool.

			s.				s.
1877.	May	1	+ 0.1	1877.	May	13	— 0.7
,,	,,	2	+ 0.3	,,	,,	14	— 0.7
,,	,,	3	+ 0.3	,,	,,	15	— 0.6
,,	,,	4	+ 0.2	,,	,,	16	— 0.5
,,	,,	5	+ 0.2	,,	,,	17	— 0.4
,,	,,	6	+ 0.2	,,	,,	18	— 0.0
,,	,,	7	+ 0.2	,,	,,	19	+ 0.0
,,	,,	8	+ 0.2	,,	,,	20	+ 0.1
,,	,,	9	— 0.0	,,	,,	21	+ 0.2
,,	,,	10	— 0.2	,,	,,	22	+ 0.4
,,	,,	11	— 0.3	,,	,,	23	+ 0.5
,,	,,	12	— 0.6				

Of course, in the case of systems like the one at Greenwich and our own, where the error is made zero each day, it is probable the daily variations in the signals will be greater than the differences of the daily errors given above. From the comparison of such data as the writer has been able to collect, there seems to be no just reason for supposing that we have not now reached the standard of accuracy in the daily signals distributed, which characterize the best of the European time services.

The only outstanding correction is that for barometric variation, and this, in our case, is treated as part of the accumulated error.

The Extension of the Time Service.

The Observatory, previous to bringing the matter to the attention of the Western Union Telegraph Company, made inquiries at such cities as it seemed likely would be representative New England cities, and at the same time distributed a pamphlet on Standard Public Time, together with a circular letter inviting attention to the subject, among the municipal officers of about one hundred New England cities and towns. The response thus far has been most encouraging; and, upon a presentation of the matter to the officers of the Western Union Telegraph Company in New York, arrangements were discussed, which, it is hoped, will soon enable the Observatory, through the aid of this company, to transmit its signals to all the commercial and manufacturing centres in New England.

That part of the United States is not too large to have all of its railroads and commercial interests regulated by a common standard, and there seems to be no section of the country where there are so many factories in which so large financial interests are concerned with the commencement of work at established hours.*

It is true most of these places receive the Observatory signals; but they receive them through the courtesy of the railroads or of the Telegraph Company. They are not delivered with the system or the accuracy which would be creditable to the service, although the jewellers in some of these towns parade the fact that they have "Cambridge Time." In one instance, for example, the three leading jewellers advertised in this manner. Inquiry elicited that the last time signals were received three weeks since; and, as a matter of fact, the clock of the three having the smallest error was forty seconds fast.

The railroads have unofficially remarked the desirability of having a definite arrangement with the cities, so that the cities might share, to some extent, the cost of the signals to the railroads themselves.

The Western Union Telegraph Company has been conspicuously public-spirited in all matters relating to science; and it would be a satisfaction to them to do systematically what is now inadequately carried out. In any extension of the Time Service, it would not be necessary to alter our local arrangements. Indeed, as they are at present arranged, we may congratulate ourselves upon their economy, since the jewellers receive a current every two seconds, and are paying a little more than half of the equivalent for the tariff in the British "Postal Guide" for an hourly current in London. The City of Boston pays but one-half of the amount appropriated by other cities of the United States for the same service. It is doubtful whether the Observatory receives a repayment from the city for its services; and it might, with propriety, urge an increase of $500 per annum on the amount now paid by the city, since many private firms use the city time, who would otherwise be subscribers to the Observatory scheme.

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* *Extract from "A Report of the Special Committee of the Common Council of Cincinnati, on Standard Public Time."*

"Professor Airy, in charge of the Greenwich Observatory, says: 'I have, indeed, always considered it a very important duty of the National Observatory to promote, by utilitarian aid, the dissemination of a knowledge of accurate time, which is now really a matter of very great importance. I must allude to Mr. Jones's system of regulating clocks by galvanic current, a most excellent plan, of which the people of some of our Northern cities have seen the benefit, and have taken advantage. I must say that, indeed, London is very far behind in this matter. I may tell you that my friend, Mr. W. de la Rue, estimates the annual saving to his firm by having exact time, and enforcing strict attendance on his workpeople, at £300 (besides some savings of gas and coals not taken into account), which is an amount that would otherwise be entirely lost; and of this he is able to make a return to his workpeople, in the way of additional privileges as respects holidays. Think only of £300 per annum being thus saved in one establishment alone, and then consider what would be the saving in London if all establishments of similar magnitude could save a like amount.'"

In conclusion, the writer would respectfully recommend that, in the event of the extension of the service, the Observatory should discourage the use of local time in other cities than Boston, since one of the chief advantages in the extension would consist in having the same absolute time in the various cities; and that the Observatory should offer to advise with the more distant subscribers as to the best means of rendering the signals available, whether by a simple telegraphic sounder, or connection with the Fire Department bells, or dropping a time-ball, or the control of a clock, — the cost in each case being based upon the outlay of the Observatory and of the Western Union Telegraph Company; and that the support of the Observatory be given to an arrangement for dropping a time-ball in the port of Boston. There seems to be no other single act which brings a time service so conspicuously before the public. In so doing, we should only follow the example of other great observatories both at home and abroad.

Respectfully submitted.

LEONARD WALDO,
Assistant.

HARVARD COLLEGE OBSERVATORY, NOV. 20, 1877.

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ANNUAL REPORT

OF THE

DIRECTOR

OF

HARVARD COLLEGE OBSERVATORY.

Presented to the Visiting Committee
November 14, 1878,

BY

PROFESSOR EDWARD C. PICKERING.

FEB 1879
BODLEIANA

CAMBRIDGE:
PRESS OF JOHN WILSON AND SON.
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REPORT

OF THE

DIRECTOR OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE

FOR 1877–78.

TO THE PRESIDENT OF THE UNIVERSITY: —

SIR, — During the past year, both of the large telescopes belonging to the Observatory have been kept actively in use. It would be most unfortunate that either of these superb instruments should again be idle, or be employed without the hope of reducing the observations made with it, as has been the case in past years. Even now, the expenditure involved in using both instruments considerably exceeds the income of the Observatory, which must be enlarged unless the use of one telescope at least is greatly restricted. But it is hoped that the results of the year's work, which are stated below, will induce the friends of astronomy to prevent the recurrence of this necessity.

I shall first describe the work of the large equatorial telescope, and the various operations connected with it; then the observations made with the meridian circle; and afterwards the extension in the distribution of standard time signals, the progress made in reducing and publishing the past observations, the condition of the library, the present state of the attempt to increase the income of the Observatory, and the work proposed for next year.

The equatorial observations have been made under my own immediate direction, by Messrs. Searle and Upton, and by myself. The East Equatorial has been used on two hundred and thirty-nine nights during the year ending Oct. 31, 1878, mainly in a continuation of the photometric work projected last year. About 18,000 photometric observations have been obtained (22,000 in the fifteen months during which the telescope has been at work).

The light of all the known satellites, except the two inner satellites of Uranus, which are too faint for observation with our instrument, has been carefully measured. The relative light of the components of all known double stars of the fifth magnitude or brighter, and visible in this latitude, has also been determined.

Four comparisons constitute a set, and the observations of each star comprise at least ten sets. Moreover, each star has been observed on three or more nights, and by two — or oftener by three — observers, to avoid errors due to the condition of the air or to individual peculiarities.

Other precautions have been taken to guard against various systematic errors which were from time to time apprehended. A careful study of the work shows that the probable error of the final results amounts only to about one-twentieth of a magnitude. Some sources of error, which may seriously influence ordinary estimates of stellar magnitude, have been detected. It appears that the proximity of a bright star may affect the estimate of the light of a faint star to the extent of two or three magnitudes! In the present series of measurements, this source of error is avoided.

By combining a spectroscope with a photometer like that used in the work just described, various parts of the spectra of β *Cygni* and γ *Andromedæ* have been examined, and the progressive increase in the relative light of their blue components towards the more refrangible end of the spectrum has been clearly shown.

The measurement of the very faint test objects selected and in part observed last year is now completed. The constant of the photometer with which these observations were made, has also been redetermined with great care.

One of the most important series of the equatorial observations of the year relates to the eclipses of Jupiter's satellites. Much value was formerly attached to these phenomena, as a means not only of determining the orbits of the satellites themselves, but of measuring the distance of the sun or the velocity of light, and of obtaining terrestrial longitudes. But for these purposes the observation of the mere appearance or disappearance of a satellite cannot well be made sufficiently exact. Large differences occur between the results of the work done by different observers or with different instruments. The state of the atmosphere at the time of any particular observation may also greatly affect it. Errors of this kind are much lessened by photometric observations of the satellites, as they gradually enter or emerge from the shadow of Jupiter, using the planet itself or another satellite as a standard. Each comparison thus obtained gives an independent determination of the time of the eclipse, free from the errors due to the condition of the air or the power of the telescope employed, and less likely to be affected by personal equation than the observation of a disappearance or reappearance. Since June 23, 1878, twenty-three eclipses have been observed, nine of them with both the East and West Equatorials. These thirty-two series comprise over eight hundred observations. Omitting those required to determine the full brightness of the satellites just before or just after their eclipses, there remain nearly three hundred from each of which the time of an eclipse may be deduced. This gives on the average nine observations in each series; and, supposing the value of each observation to be only equal to one of those usually made, gives us in one year an amount of material which it would ordinarily require nine years to collect. This estimate does not take into account the numerous cases in which many photometric observations of an eclipse may be obtained when the actual disappearance or reappearance cannot be observed, owing to clouds or accident of any kind. Moreover, by the ordinary method, an observation during twilight can have little value, while good photometric observations may be made as well then as at any other time. It is even possible to make them before sunset.

For the development, by the various kinds of work above described, of a branch of science which has heretofore received little attention, it has been necessary to devise a new class of instruments. These are designated in the records of the Observatory by the letters of the alphabet, the first which was constructed being called Photometer A, and the last Photometer O. The work of the year has mainly been done with Photometers H and I. Photometers L and M, which have as yet not been brought into systematic use, require special notice. Photometer M consists of a Rochon micrometer, in which the images of the two stars may be rendered equal in brightness by a Nicol. The positions and distances of the components of double stars may thus be measured with great precision, while the systematic errors occurring in measurements of the usual kind may be almost wholly eliminated. Photometer L is intended to measure the brightness, positions, or distances of any two stars the angular separation of which lies between 6′ and 40′. It resembles a double-image micrometer or heliometer, except that the full aperture of the telescope is used. The loss of light and deterioration of the images in these instruments is thus avoided.

By the liberal gifts to which reference is made on page 13, the construction of the photometers just mentioned, especially of those adapted for micrometric work, was rendered possible. Great credit is also due to Mr. George B. Clark, of the firm of Alvan Clark & Sons, without whose ingenuity and skill their construction would have been attended with great difficulty.

Besides the photometric observations made with the East Equatorial, it has occasionally been used in determining the places of asteroids, and for other purposes.

All the available telescopes of the Observatory were in use during the transit of Mercury last May, for observations of the diameter of that planet, as well as of its ingress and egress. The weather, unfortunately, seriously interfered with these observations. Photographs of the transit were also taken in co-operation with the U. S. Naval Observatory, upon dry plates sent from Washington, and returned for development and measurement. A few additional photographs were obtained, for preservation at the Observatory.

No expedition was sent from this Observatory to observe the Total Eclipse of the Sun on July 29, 1878. In view of the pressing need of money for our immediate work, I did not feel justified in an expenditure the results of which might be negative. Aid was freely offered to other observers, by the loan of any instruments not in use at the Observatory. Three or four parties availed themselves of this opportunity, and instruments valued at two or three thousand dollars were thus used during the Eclipse. These instruments have been returned in good condition, and their use has been handsomely acknowledged in the printed reports. Leave of absence was given at this time to Mr. Leonard Waldo, who observed the Eclipse in Texas, and to Mr. Upton, who joined Professor Stone's party in Colorado.

A new method of measuring the transparency of the air has been employed during the past two months, by comparing the light of stars near the zenith and horizon. This promises to furnish a simple means of determining the coefficient of atmospheric absorption at different times and places.

Observations with the meridian circle have been made on one hundred and fifty-eight nights during the year. The observer in charge of the instrument has been, as in previous years, Professor W. A. Rogers, who has been assisted in reading the microscopes by Mr. J. F. McCormack. The observations of the stars between 50° and 55° north declination have continued without interruption. This great work, which has been carried on for eight years, will be completed by the end of December, 1878. Of eight thousand stars to be observed, only one hundred and thirty-four remain, all situated between 23^h and 5^h of right ascension.

Observations of a list of two hundred and fifty-eight stars, drawn up by the U. S. Coast Survey, at whose request the work was undertaken, were begun in January, 1878. Six observations of each star have thus far been made, with four or five exceptions. The method of observation in use here allows the observations to succeed each other at very short intervals, so that, although in some cases several of the stars are situated within a single minute of right ascension, the whole work will be completed by the end of 1878.

The whole number of observations made during the year is as follows: —

Zone Stars	1,510
Fundamental Stars	1,338
Coast Survey Stars	1,285
Miscellaneous observations	167
Total	4,300

The chronograph sheets have all been read as far as October, 1878; and the results, together with the circle readings, have been copied in permanent form. The reduction of last year's observations of the planet Mars, and of the comparison stars in the lists of Mr. Gill and Professor Eastman, has been completed.

The reductions of the Polar Catalogue of 1872–73 are completed, but considerable work still remains to be done in preparing the results for the press.

The observations of 1874–75, made upon the stars of the General Catalogue of Vol. X. of the Annals of the Observatory, have been reduced, and the work is now in process of printing. The discussion of these observations is still to be made.

The reduction of the observations made upon the stars of the Coast Survey has been somewhat more than half completed by Mr. Upton, who has this work in charge. The fundamental stars upon which these observations depend are one hundred and sixteen in number. The co-ordinates of these stars for 1878.0 have been derived from the following authorities: —

Greenwich	from 1870 to 1875, inclusive.
Washington	,, 1870 to 1874, ,,
Cambridge	,, 1871 to 1875, ,,

The positions taken from these sources have been reduced to the system of the Berlin Ephemeris of five hundred and thirty-nine stars, by applying corrections both for constant and for systematic deviations from this system.

A series of photometric observations have also been made, in which Professor Rogers has estimated the brightness of stars seen with various apertures. This furnishes a means of reducing to absolute measure the scale of magnitudes he has employed in the zone observations.

The general management of the time-service remains in charge of Mr. Leonard Waldo, who has been assisted, since July 1, by Mr. Frank Waldo. The signals have been distributed over a wider area than before. By the intervention of railroad and telegraph companies, they now reach Bangor, Lennoxville in Canada, Albany, and New York. The most important extensions of the service consist in the arrangements by which the signals are now sent through the northern part of Massachusetts to North Adams, and in the establishment of a time-ball at Boston. This last enterprise was made practicable by the liberal co-operation of the Equitable Life Assurance Co., and of the United States Signal Service. The ball is of copper, four feet in diameter, and weighs about two hundred and fifty pounds. It has a fall of about fifteen feet, and is held in place, when raised to the top of its mast, by a powerful electro-magnet. It is released at noon by the clock at Cambridge, which acts automatically through the telegraph line to the building of the Equitable Life Assurance Co., on Devonshire Street, where the ball is mounted. If, from any cause, the ball fails to drop at noon, it is released, in the manner just explained, at precisely five minutes after noon. Since July 12, a record of its performance has been kept, which is compared below with the records for a period of five years of the performance of the time-ball at Deal, England, dropped by the Royal Observatory at Greenwich. The figures show the percentage of results of each kind mentioned: —

	Time-ball at	
	Boston.	Deal.
Dropped by telegraph at $12^h\ 0^m$	89	86
,, ,, ,, ,, $12^h\ 5^m$	7	
,, ,, hand	1	9
Failed to drop	3	5

The success attained in the working of the time-ball at Boston is largely due to the zeal and skill displayed by Mr. Orrin Parker, Sergeant U. S. Signal Service, who has been stationed at Boston, and in charge of the ball since its establishment. He has been efficiently assisted by Messrs. J. H. Righter and F. W. Conrad, also of the Signal Service.

Arrangements are in progress with the Western Union Telegraph Co., for the distribution of time-signals to various cities desirous of receiving them from the Observatory. Inquiries have been made of the superintendents of New England railroads with regard to several points connected with proposed extensions of the time-service, the answers to which may be stated in brief as follows: —

Ninety per cent of the railroads consider it a convenience to travellers to have all trains run by the same time throughout New England. Ninety-three per cent consider that a uniform standard of time distributed over their lines would lessen the risk of accident; ninety-three per cent advocate a general distribution of the signals over all the New England lines at the same instant of time. A recourse to legislation to produce uniformity in railroad time is not generally favored, fifty-three per cent of the roads considering that the proposed object can be best accomplished by mutual agreement. For a time to use as the standard, sixty per cent favor Boston (the signals now sent from the Observatory), seventeen per cent New York, and the rest various intermediate standards. The standard now in use is in forty-seven per cent of the cases Boston time; in twenty-three per cent New York time; and in others various local times.

It may here be observed that no inconvenience can follow from the use of one standard of time over a large tract of country, even if it differs several minutes from the local time; and again, that if the use of local time is preferred, the same signals will still serve different places, which have only to consider the moment at which a signal is received as differing by a fixed number of minutes from noon or any other moment of Boston time (for example) selected for the transmission of the signal.

The new clock-room, described last year, has given complete satisfaction. Some changes have been made in the telegraphic circuits, so that either of the two lines from Cambridge may be available for dropping the time-ball as well as for distributing the signals. Messrs. E. Howard & Co. have placed one of their clocks, No. 191, upon the granite pier in the clock-room mentioned last year as designed for this purpose. This clock will be available as a substitute in case of need for the standard mean-time clock, Bond 394. Its performance is good, and it is kept within a small fraction of a second of the standard clock. The error of the standard clock, Bond 394, at 10 A.M. of each day (determined by clock comparisons, and of course not known with certainty when a long period of cloudy weather has occurred), has exceeded seven-tenths of a second on two days only during the year. Since July 1 it has exceeded one-tenth of a second on nine days only.

The reduction and publication of the past observations has been pushed as vigorously as our means permitted during the year. The two gaps in our series of Annals have been filled by the publication of Volume IV. Part 2, and Volume IX., so that the set is now complete from Volume I. to X. The amount of material still to be published will fill nine or ten volumes; that is, it will occupy almost as much space as all that the Observatory has published for thirty years past. If the observations were published in detail, as is the case at the Observatories of Greenwich and Washington, and as has been done heretofore at this Observatory, over a dozen volumes would be required to contain the observations already made. This includes only the material of whose publication there can be no question. Much remains which will not be issued, the lapse of time and other causes having seriously impaired its value.

This accumulation of valuable observations, the result of years of persistent labor, and of the expenditure of many thousands of dollars, is at present liable to destruction by fire or other accident. There is no absolute security from this danger until the volumes are published and distributed. The greatest need of the Observatory at the present time is the means of preparing this material for the press. By a sufficient increase in our clerical force, the expense need not be very great. It is not good economy, however, that much of my own time and that of my assistants should be spent on work which may be done by any copyist, as is now the case. Delay in publication not only diminishes the value of the work, but greatly increases the difficulty of preparing the manuscript for the printer. A delay of several years often renders it almost impossible to supply the details necessary to give the volume its greatest value. Moreover, there is danger that good work done here may be needlessly repeated elsewhere, if its publication be long delayed.

It seems hard that Professor Winlock, although for nearly ten years Director of this Observatory, did not live to see any of his own observations published, or even to complete the work of his predecessors. To avoid the increased accumulation of unreduced observations, a system of book-keeping has been introduced in the equatorial work, by which every day the observations of the previous evening are reduced as far as possible, and the results entered on sheets ready for the printer. This has enabled us to begin already the publication of the photometric work of the equatorial, although the entire system of observations is not yet completed.

During the past year an approach for wagons to the west wing of the Observatory has been laid out. A gardener has been employed for a large part of the summer in various improvements of the grounds, which have not been charged to the Observatory or College. No important change has been made in the building. Some upholstering, refurnishing, and additional book-shelves are much needed in the library and computing rooms. More pressing demands have prevented such an expenditure as is desirable on the library, and no shelf room now remains for the later accessions. The instruments remain in good condition, and have not suffered the deterioration to which they are liable when not used. The convenience of using the large equatorial has been greatly increased by the addition of large finding circles, and during the present month by the substitution of a new tail-piece.

The peculiar advantages already enjoyed by this Observatory make it apparent that even a comparatively small increase of its resources may reasonably be expected to yield more immediate and valuable returns than can in any ordinary cases be looked for from money laid out in the encouragement of science. Besides the libraries, scientific collections, and laboratories of the University, we have the similar institutions of Boston close at hand. Instrument makers of the very first rank in their profession are established in the neighborhood, and the instrumental equipment of the Observatory is in many respects unsurpassed elsewhere. Funds for the publication of observations which have been made ready for the press, and for the payment of current expenses (such as repairs, fuel, lights, and stationery), are already at our disposal. The true test of the power of an observatory, however, must be the income which is available for its strictly scientific work, after the mere cost of its maintenance has been paid. The amount of work done will obviously be directly proportional to this surplus, so long, at least as it remains insufficient to give full employment to the principal instruments of the institution.

In the present case, any increase of the income of the Observatory may be directly applied to the promotion of scientific researches, and will accordingly yield unusually large returns in the form of published observations.

A year ago, the Visiting Committee, recognizing the great need of an increased income for the Observatory, undertook to supply this want. To these gentlemen my best thanks are due for their vigorous measures, which promise to instil new life into the Observatory. I must especially mention Messrs. Agassiz, Amory and Bowditch, as it was their energy and enthusiasm which overcame all the obstacles which presented themselves. A subscription was started to raise five thousand dollars a year for five years, in sums not less than fifty dollars annually. It was hoped that if the immediate needs of the Observatory could thus be met, results would be obtained that would render it easy hereafter to secure an increase in our permanent endowment.

A circular was distributed asking for subscriptions, payable in case the entire amount was raised. During the year ending Oct. 31, 1878, to which this Report relates, subscriptions amounting to thirty-two hundred dollars annually have been made. Since then, the subscription has proceeded very satisfactorily; and it is confidently expected that in a short time the entire amount will be received. As a complete list of the subscribers cannot, therefore, be given, it appears best to defer until next year's Report an acknowledgment of the individual subscriptions. I desire at this time to express to those who have already promised their assistance the great obligation the Observatory is under to them for the generous manner in which they have responded to its needs. The assurance of friendly sentiments toward the Observatory given by those who were unable to aid in this work has also been most gratifying.

Three subscriptions, by Mrs. Forbes, Mrs. Brooks, and Mr. Appleton, were made without the condition that the entire sum should be secured. This generous action has permitted the construction of the new photometers referred to above.

If the subscription succeeds, both telescopes will be kept in active use. The Equatorials will be employed in photometric observations of Jupiter's satellites, of variable stars, and of the standards with which they have heretofore been compared. A chart will be prepared of all the stars in the immediate vicinity of the pole, and standards for future reference of star magnitudes will be measured. The two micrometers noted above, if they accomplish all they promise, will open wide fields of work. It is hoped that observations with them may be reduced to a routine, and the work of the large telescope carried late into the night by observers employed for this purpose only. Next autumn, special attention will probably be paid to the planet Mars, which will then be more favorably situated for observation than will again be the case for many years. An extended plan of work has been laid out for the Meridian Circle. It is proposed to determine the absolute positions of a series of standard stars, independently of previous observations. The errors now carried from one catalogue to another will thus be eliminated. This will involve observations at short intervals during a greater portion of the day and night. The reduction of the work with both instruments will be kept up with the observations, as far as possible. It is hoped that at no distant day the past observations will be published, and new volumes of Annals issued within a few months of the completion of the observations.

It constantly happens that accurate measures of length are required in various portions of our astronomical work. The Prime Vertical Room is well adapted for this purpose, and will probably be fitted up for it. At present, it is used only for storing the duplicates of the Library, and other works not often consulted.

To recapitulate: Both telescopes have been in constant use, the distribution of standard time has been extended, and much progress has been made in the reduction of the past observations; but the present income of the Observatory will not permit this rate of work to be maintained. An increase of five thousand dollars a year for five years has been solicited, and if obtained will, during that time, more than double the scientific results of the Observatory, whose endowment, grounds, buildings, instruments, and library, represent a sum of more than $300,000. But little remains to be promised in order to secure the whole. If this can be done, rapid progress can be made in the publication of the accumulated mass of past observations, which are in danger of destruction by fire so long as they remain unprinted; and an activity can be maintained throughout the institution commensurate with its reputation at home and abroad.

EDWARD C. PICKERING.

THIRTY-FOURTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

PRESENTED TO THE VISITING COMMITTEE
DECEMBER 5, 1879,

BY

EDWARD C. PICKERING.

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1880.

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THIRTY-FOURTH

ANNUAL REPORT

OF THE

DIRECTOR OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.

1878–79.

To the President of the University: —

Sir, — My last Annual Report concluded with an account of the undertaking, then in progress, to relieve the immediate needs of the Observatory by a subscription of five thousand dollars a year for five years, and with an expression of the hope that this attempt would shortly be successful. I have now the gratification of stating that the subscription was, in fact, soon afterwards completed, and of returning my hearty thanks, on behalf of the Observatory, to the ladies and gentlemen who have so generously supplied its wants.

The improvement, resulting from this subscription, in the condition of the Observatory will appear at once upon the bare statement of what could have been accomplished without such aid. Even when the interest upon the invested funds of the University was much higher than at present, the means of the Observatory permitted very little scientific work to be carried on beyond that done with the Meridian Circle. Indeed, the observations made, even with this instrument, could not be reduced with the desirable promptitude, and the publication of the first observations made in 1871 and 1872 was only partially accomplished in 1877. With the diminished income of recent years, therefore, no more could be hoped for than to keep a single instrument in moderate activity, so that the use either of the Meridian Circle, or else of the Equatorial, would have been restricted to occasional observations. As it is, although the force of computers engaged in reducing the old observations made with the Meridian Circle has been increased, the following pages will show that both instruments have been actively employed. Moreover, a large amount of interesting work with the Equatorial, which was begun in the hope, but without the certainty, that means would be provided for its completion, has been reduced, discussed, and, to a considerable extent, already published. In fact, as had been anticipated, the whole sum raised by subscription has been directly applicable to the scientific work of the Observatory, so that the increase in the amount of this work has been, relatively, much greater than that in the income of the Observatory. A large part of the previous resources of the institution was necessarily consumed in providing for the repairs and the care of the buildings, and in supplying fuel, lights, and stationery. The addition to these expenses resulting from additional work is comparatively slight. Hence, any large observatory, already fully established, can always apply the additional income which it may receive more economically, and with a better prospect of attaining considerable results, than would be possible for a smaller institution of the same kind. The instruments with which an observatory is already equipped are rarely employed as constantly as they might be, if a larger endowment were provided for them, owing to the great labor involved in reducing and publishing the observations made with them; and a single superintendent can direct the work of many computers as efficiently as if their number were much smaller.

The complete list of subscribers to the fund raised for the current work of this Observatory is given below, with the amount promised annually by each for five years. The sums marked with asterisks are donations made for one year only. Conditions have been attached to two or three of the remaining subscriptions; but, even without these, the full sum of five thousand dollars a year for five years has been provided.

LIST OF SUBSCRIBERS.

Name.	Amount.
William Amory	$100
Charles F. Choate	100
Alexander Agassiz	100
E. C. Pickering	200
J. M. Forbes	100
Fred. L. Ames	$100
Nathaniel Thayer	100
Martin Brimmer	100
H. H. Hunnewell	100
T. Jefferson Coolidge	100

Name.	Amount.	Name.	Amount.
John L. Bremer	$100	W. O. Grover	$50
Charles H. Dalton	50	C. F. Adams	100
John L. Gardner	100	George Gardner	50
Misses Wigglesworth	100	F. H. Peabody	50
J. Ingersoll Bowditch	100	H. P. Kidder	100
H. A. Whitney	50	Augustus Lowell	50
G. O. Shattuck	50	O. W. Peabody	125*
Mrs. Sparks	60	Mrs. Brooks	100*
Mrs. J. M. Forbes	200	G. B. Blake	50
W. F. Cary	50	John C. Gray	100
A. C. Wheelwright	50	George Higginson	100
Mrs. A. Hemenway	100	James H. Beal	50
W. C. Cabot	50	J. M. Sears	100
James L. Little	100	Samuel R. Payson	50
R. E. Robbins	50	Robert W. Hooper	50
Miss Jane Welles	200	William D. Pickman	100
R. S. Fay	50	F. L. Higginson	50
Mrs. Anna C. Lodge	50	Charles E. Ware	50
F. R. Sears	50	Henry S. Grew	50
Otis Norcross	100	John P. Bayley	50
Charles P. Curtis	100	James Davis	100
G. W. Lyman	50	Mrs. David Sears	100
Mrs. S. Hooper	100	P. C. Brooks	100
R. C. Winthrop	50	Charles J. Paine	50
G. B. Emerson	50	Augustus Flagg	100*
T. G. Appleton	50*	John C. Phillips	100
Mrs. Shaw	150*	George P. Upham	50
W. P. Mason	100*	W. G. Weld	50
Theodore Lyman	100*	J. A. Burnham	100
E. R. Mudge	100	Stephen Salisbury	50
E. Austin	100*		

During the period covered by this Report, the large equatorial telescope has been used on almost every clear evening, and frequently, also, during the last half of the night. The observations made with it are, in part, published in Volume XI. of the Annals of the Observatory, which will be described below. Among these are photometric measurements of Iapetus, the outer satellite of Saturn, made on one hundred and one nights, in the autumn and winter of 1878–79. Similar observations had been made on twenty nights in the previous year, and the entire series furnishes a determination of the law followed by the satellite in its changes of brightness.

The photometric observations of the eclipses of Jupiter's satellites, described in my Report of last year, have been continued, and form one of the most important pieces of work recently accomplished with the large telescope. The number of these eclipses observed, in addition to those previously reported, is twenty-five, six of them with both East and West Equatorials.

An attempt has been made to furnish means for the comparison of the scales of stellar magnitude, employed by different astronomers in their estimates of the brightness of faint stars. At present, as is well known, the scale of one observer may vary considerably from that to which another has accustomed himself, and it is often difficult to know what degrees of brightness are to be understood to correspond to published estimates of magnitude. In order to do something to remedy this defect, a number of faint stars were selected for photometric observation, and a circular was distributed among astronomers, and published in the Astronomische Nachrichten, the Monthly Notices of the Royal Astronomical Society, Nature, and the Astronomical Register, requesting estimates of magnitude of the same stars, for comparison with each other and with the results of the measurements made here.

The region selected was in the immediate neighborhood of the north pole. The grounds for this choice are that throughout the northern hemisphere the stars may always be referred to for comparison with others, and that their altitude at each station is nearly invariable. The work of measurement undertaken here is complete, and the observations are mostly reduced. It is hoped that during the coming year replies to the circular will be received from many quarters, and especially from those astronomers who are accustomed to make estimates of the magnitude of asteroids.

A series of measurements of all the planetary nebulæ has also been undertaken with the large Equatorial. Their diameters will be measured, and, when they are elliptical, also the directions of their axes. The double-image micrometer, described in the last Report as Photometer M, is used for this purpose. An important test of the character of a nebula is found in its spectrum. The use of a spectroscope, however, is surrounded by difficulties, especially when the object is small and faint. A direct-vision prism has therefore been inserted between the objective and eyepiece, and each nebula examined through it. If monochromatic, the nebula presents the same appearance as if the prism was removed; but if the spectrum is continuous, its light is spread out into a luminous band. A single glance, therefore, serves to distinguish between these appearances, and to place the nebula in its proper class. The loss of light is small, and the telescope need not be pointed with accuracy.

An instrument, designated in our records as Photometer Q, has been constructed for measuring the light of the nebulæ. The comparison is here made with the image of a star thrown out of focus by such an amount that it will appear of the same intrinsic brightness as the nebula. Knowing the stellar magnitude, a simple computation serves to show what must be the magnitude of a star which, when spread over a circle one minute in diameter, would emit the same amount of light as an equal area of the nebula. We may, accordingly, describe the light of the nebulæ in stellar magnitudes, thus adopting the same unit and same scale for nebulæ and stars.

Among other photometric measurements may be mentioned a considerable number made on variable stars, and on others near them, which have been used by former observers as objects of comparison.

A short series of observations for stellar parallax was obtained last summer, and the complementary observations required for comparison with them will be made during the coming year. The stars are observed in zones according to a plan devised by Mr. Searle; a part of the observations have been made by him, and the remainder by Mr. Wendell.

Miscellaneous work has also been done with the telescope. Several asteroids have been observed by Messrs. Rogers and Upton, and a long series of observations of the position of Comet II. 1879 has been made by Mr. Wendell.

Some minor improvements have been made in the large telescope, by which its efficiency is materially increased. The most important of these changes is the addition of new microscopes for setting the telescope in declination.

Observations have been obtained by Professor Rogers with the Meridian Circle on one hundred and seventy-one nights between November 1, 1878, and September 23, 1879. The observation of the zone of eight thousand stars between 50° and 55° north, undertaken by this Observatory as its share in the determination of the position of the stars of the northern hemisphere, was completed on January 26, 1879. It has occupied a large part of the time of the observer, Professor Rogers, for over eight years, and forms one of the largest astronomical undertakings which have been carried to completion in this country. Some years will still be required to complete the reduction and publication of this work.

The observations of the list of two hundred and fifty-eight stars, undertaken at the request, and partially at the expense, of the United States Coast Survey, were completed on January 5, 1879.

During the months of November and December, 1878, a list of ten stars, furnished by Professor David Gill, was observed, for the purpose of ascertaining the personal equation between bright and faint stars, the results of the observations of the Mars comparison stars observed in 1877 requiring an investigation of this kind in order to make them available.

Observations were also made —

(*a.*) To determine the personal equation between bright and faint stars, the reduction in magnitude being made by means of diaphragms of varying diameters.

(*b.*) To determine the personal equation between bright and faint fields of the telescope.

(*c.*) To determine the personal equation between observations made by tapping the chronograph key with the thumb and with the forefinger.

Since February 15, 1879, the Meridian Circle has been devoted to the determination of the absolute co-ordinates of one hundred and eight stars of the first, second, and third magnitudes.

The following outline of the arranged programme of the work will indicate its general character: —

(*a.*) The determination of the right ascension of the sun by means of its declination observed at meridian transit. The observations are distributed as nearly symmetrical as possible about the two equinoxes, and extend over a period of eighty days near the vernal equinox and eighty days near the autumnal equinox.

(*b.*) The determination of the obliquity of the ecliptic by observations near the solstitial points. The observations for this purpose are limited to twenty days in June and twenty days in December.

(*c.*) Ten observations of each star near each equinox. In order to make the observations in right ascension as strictly differential as possible with respect to the sun, the working lists are so arranged that the stars to be observed at a given time shall have nearly the same declination as the sun. The observing list of stars of this class is limited to stars within about 30° of the equator.

(*d.*) Stars north of 30° declination are connected with the primary system by observations extending from May to August.

(*e.*) The instrumental constants depend upon observations of Polaris only. For this purpose this star is observed at each culmination as often as possible. For right ascension, it is observed over a close group of twenty-five wires, which are symmetrical with respect to the equatorial groups. For the determination of the equator-point correction of the circle, twenty separate determinations of the declination are made at each transit, four microscopes being used for each setting of the telescope. The actual number of separate determinations is 2,317. A complete observation of Polaris requires about forty minutes. The time required for an equatorial star is about four minutes.

The number of observations made during the current year is given in the following table: —

Class.	Number of Observations.
Gill's List, &c.	291
Zone Stars	400
Coast Survey Catalogue, 1878–79	636
Fundamental Stars, 1879	1,454
Polaris	130
Sun	98
Total	3,009

It will be noticed that the number of observations of Polaris and of the Sun is comparatively large, since they were contained in a period of a little over six months.

Before beginning the absolute work in 1879, the following changes in the instrument were made: —

(1.) A new transit-reticule was inserted, having groups of five, nine, and five wires. For the polar group, the middle group was still further divided by the insertion of sixteen additional wires, terminating in the centre of the field.

(2.) A new polarizing eye-piece was constructed for solar observations.

(3.) Inasmuch as the micrometer screws furnished with the instrument required quite large corrections, it was deemed economy to substitute new micrometers for them. Accordingly, Mr. George

B. Clark, of the firm of Alvan Clark & Sons, made four new ones, which, upon investigation, were found to have no error exceeding 0.05″.

By means of a swinging arm carrying two eye-pieces, the power of each microscope can be nearly doubled at will.

A very large number of observations have been made for the determination of the error of each 15° division of the circle, and provision has been made for the examination of each 5′ space by the construction of a separate arc of 15°, graduated to 5′, which, after the investigation of its errors, will be used as a constant arc of reference.

The present state of the reductions is as follows: —

(1.) Zone Observations. Besides the work described in the Report of last year, the chronograph sheets of the present year have been read, and the observations of the fundamental stars for 1878 have been completely reduced. They rest upon the new Pulkowa system.

(2.) Polar Catalogue, 1872–73. This catalogue is nearly ready for publication, but the discussion of the observations is yet to be made.

(3.) The reduction of Coast Survey Catalogue of 1878 is completed, and the resulting positions have been communicated to the Superintendent of the Survey. This work is also nearly ready for publication.

(4.) General Catalogue, 1874–75. Over two hundred pages of the volume containing these observations are in type, and its issue from the press may be expected within a short time.

(5.) Fundamental Catalogue, 1879. The work of reduction has not proceeded very far, owing to the press of work in other directions. The chronograph sheets have been read off, and the means of the times of transit and of the circle readings have been taken for about one-half of the observations of this series. The general constants required for the reductions have also been computed.

A work of some magnitude has been undertaken during the past year in the determination of the light of all the stars visible to the naked eye in this latitude. For this purpose a catalogue of about four thousand stars has been formed, arranged in the order of right ascension, and brought forward to 1880.0. It includes all the stars in the Uranometria Nova of Argelander, all the stars in the Atlas Coelestis Novus of Heis, and in the Durchmusterung to the sixth magnitude inclusive, and those in Behrmann's Atlas des südlichen gestirnten Himmels north of 30° S. To these have been added a few stars from other authorities.

As most of these stars are inconspicuous objects, much time would be lost in identifying them in the field of a photometer mounted on an ordinary stand. This is avoided by observing them in the meridian as with a transit instrument. The photometer consists of a horizontal telescope pointing to the west, and having two objectives. By means of two prisms mounted in front of the telescope, the pole star is reflected into one object-glass, and the star to be measured into the other. The cones of light are made to coincide by a double-image prism, the extra images being cut off by an eye-stop. The star to be measured is thus seen in the same field with the pole star, with the same aperture and magnifying power. Many of the errors to be apprehended in the use of the Zöllner photometer and other instruments in which the comparison is made with an artificial star are thus eliminated. The most important are those due to the different appearance of the real and artificial stars, the variation of the latter, and the varying opacity of the atmosphere. To determine the relative transparency of the air at different altitudes, a list of a hundred circumpolar stars has been prepared, to be observed at both upper and lower culminations. Progressive changes in the light of the pole star may thus, also, be detected and eliminated. This method of observation may evidently be applied to any other form of photometer.

Many practical difficulties were found in the construction of this photometer, and much time was spent in overcoming them and in making the preliminary observations. An assistant is required to set the reflecting prism, read the circles, and keep the record. Two persons can thus measure about forty stars in an hour. Each of the four thousand stars will be observed on three evenings, four settings being made each time. Three observers will take part in the work, to lessen the effect of personal errors.

The meteorological observations have been continued on the system arranged at the beginning of 1877, but it now becomes a question whether this part of the routine labor of the Observatory should be maintained after the close of the present year, which will complete a period of forty years since Professor Bond began observations of this kind in Cambridge. The great number of meteorological stations established in late years, and their superior facilities for performing their work satisfactorily, make the utility of similar work at institutions like this Observatory, where it cannot receive close attention, at least doubtful, from a scientific point of view. There are certain points of connection between meteorology and astronomy which might be usefully investigated here; but this would require special observations of a kind differing considerably from those wanted in the preparation of ordinary meteorological statistics. Again, inquiries with regard to the rainfall and the general character of the weather at particular times are occasionally addressed to the Observatory, and still more rarely the mean temperature is inquired for. These questions might be answered as well as they can be at present without keeping up the present form of meteorological record. By endeavoring to supply only those kinds of information which experience shows to be most frequently in demand, the work might apparently be much simplified, with no loss either to the scientific or to the general public. Unless, therefore, the proposed abandonment of this record should prove to be open to objections which have not yet suggested themselves, it is probable that the full meteorological record hitherto kept up will be discontinued. In any case, it will be desirable to collect and publish the results obtained during the past period of forty years.

The time-service has been conducted in a satisfactory manner during the past year, as heretofore, by Mr. Leonard Waldo, the immediate care of the clocks being intrusted to Mr. Frank Waldo. The signals have been distributed with so small an error that in but three, or possibly four, cases have they differed at 10 A.M. by more than two-tenths of a second from the true time as determined from the standard clock of the Observatory. The time-ball continues its excellent record of the previous year. Since the 1st of January, accidents have caused a small error in its fall on two days only, and on three days it has been dropped at 12h. 5m. 0.0s.

The publication of two new volumes of the Annals of the Observatory was undertaken during the past year. Volume XI. contains the results of over twenty-five thousand photometric observations, principally made with the large Equatorial. The first part of the volume has been completed ; the second part is now going through the press, and will be distributed during the coming year. Part I. contains a description of the instruments employed, a journal of the observations, a discussion of the relative light of Jupiter and Venus, Mars and Saturn, and a comparison of the relative light of the components of the principal double stars. These were measured with care, taking various precautions to eliminate systematic error. The light in different parts of the spectra of certain colored stars was also compared, and a discussion given of the effect of the proximity of a bright star. The results are finally compared with the magnitudes estimated by Struve. Part II. of this volume will contain an investigation of the photometers in which the light is measured by a small telescope with variable aperture. All of the known satellites, except the inner satellites of Uranus, have been observed with these instruments. A series of very faint companions to bright stars have also been measured, and the results discussed in this volume. A large part of Volume XII., which contains the observations with the Meridian Circle in 1874–75, is in type, and will be completed during the coming year. The stars to which the work relates are the same as those the places of which are given in Volume X. of the Annals.

A beginning has been made of a series of improvements much needed in the Observatory building. Additional shelves have been put up in the Library, increasing its capacity for books more than one-half. This room and the East Computing Room have been repainted and papered, the furniture re-covered, and the engravings re-framed. New carpets are now needed in these rooms, and the second story of the West Wing should be similarly re-fitted. Both stories are required for the accommodation of the present force of computers. The Prime Vertical Room, which for many years has been used only for holding books not in use, has been partially fitted up for the accurate measurement of short distances.

Extensive repairs have been made during the past year in the shutters of the large dome, and in the machinery for moving them.

The grounds and avenue have been kept in order mainly at the expense of the Director. Various minor improvements have been made in the way of drainage, re-sodding, extracting roots, &c.

The entry of the West Wing of the Observatory is obstructed by the wooden pier of the West Equatorial. This pier is unsteady, and is a source of danger from fire. It is proposed to replace it by two brick walls, connected above and below so that the entry shall pass between them. This will greatly improve the appearance and convenience of the passage, and will increase the steadiness of the telescope.

The Observatory is indebted to Mr. Joseph Coolidge for the gift of a valuable pocket chronometer (Richard 112). It is of a rare and curious construction, and remarkable for the perfection of its workmanship. It will prove a useful addition to the instruments of the Observatory.

EDWARD C. PICKERING, *Director.*

THIRTY-FIFTH

ANNUAL REPORT
OF THE
DIRECTOR
OF
THE ASTRONOMICAL OBSERVATORY
OF
HARVARD COLLEGE.

PRESENTED TO THE VISITING COMMITTEE
DECEMBER 6, 1880,

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THIRTY-FIFTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

PRESENTED TO THE VISITING COMMITTEE
DECEMBER 6, 1880,

BY

EDWARD C. PICKERING.

CAMBRIDGE:
UNIVERSITY PRESS: JOHN WILSON AND SON.
1881.

THIRTY-FIFTH

ANNUAL REPORT

OF THE

DIRECTOR OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.

1879–80.

To the President of the University: —

Sir, — The past year has been one of unusual activity at the Observatory. The funds which were recently subscribed for the temporary support of its scientific work have, as was expected, removed all present apprehension of the necessity of restricting either of the principal instruments to merely occasional observations. In fact, while both the Equatorial and the Meridian Circle have continued in regular employment, the increase of our means has permitted many important researches to be conducted with the smaller instruments without interference with the activity of the chief telescopes. I trust that it will appear hereafter that the entire work possesses an interest, and has been pursued with an economy of time and labor, which will do credit to the liberality of those who have provided the necessary means for its continuance. Many of the subscribers have paid in one sum the entire amounts promised during five years. This furnishes the Observatory for the present with an additional fund, the income of which will increase the total amount of the subscription. Of the Annals of the Observatory, the second part of Vol. XI. and Vol. XII. have been completed and distributed during the past year. Good progress has been made with the reductions of recent observations; and many of those made in earlier times have been prepared for publication. The present report will describe successively the work done with the large Equatorial and its subsidiary instruments, with the Meridian Circle, and with the

Meridian Photometer; the work connected with the distribution of the standard time signals; the publications of the past year, the volumes now in preparation, the condition of the library, and the improvements in the buildings and grounds.

Large Equatorial. — The observations with this instrument and with others subsidiary to it may be classified by subjects, as follows: —

Satellites of Mars. — While, during the opposition of 1877, the principal observations of these satellites made here were photometric, during that of 1879 their position with respect to Mars was made the chief subject of inquiry. A longer series of observations was obtained here during the past year than was made elsewhere; and, so far as I am aware, Deimos was last seen at this Observatory. The method of reducing the light of Mars by colored glass — which was first employed here during the micrometric measures in 1877 — was again used. It was also adopted during the recent opposition at Washington, and at various foreign observatories. The observations were made almost exclusively by Mr. Wendell and myself. They principally consisted of measurements of position angle; but many measures of distance were also made after the work had been continued for some time. The number of observed position angles of Deimos was 825, of Phobos 278, and that of observed distances 245. The probable error of one setting in the three cases was 0.°6, 0.°9, and 0.″6.

Besides the micrometric work just mentioned, many photometric measures were made, the results of which have been compared with those obtained in 1877, and published in Vol. XI. of the Annals of the Observatory. These measures appear to show that, if we assume the satellites of Mars to have a capacity for reflecting sunlight equal to that of Mars, Deimos has a diameter of about six, and Phobos of about seven miles. Deimos, as is shown by experience at various places as well as here, appeared somewhat brighter in 1879 than in 1877; and in both years it seems to have been brighter measured photometrically, and to have been more readily seen when it followed than when it preceded Mars.

Eclipses of Jupiter's Satellites. — The photometric determination of the times of these eclipses, begun in the summer of 1878, has been regularly continued during the past year. The total number of eclipses thus observed up to Nov. 1, 1880, is 119, of which 60 are of Satellite I., 26 of II., 22 of III., and 11 of IV. The results thus far obtained confirm the hope with which the work was undertaken, — that it would lead to a more precise knowledge of the times of the eclipses than had formerly been attainable. Two eclipses of Satellite I. have been compared by plotting the observations of each, and drawing smooth curves through them. The respective intervals in seconds, from the computed time of the eclipse, at which the satellite had diminished in brightness 1.5, 2.0, 2.5, 3.0, and 3.5 magnitudes, were in the first case +33, +16, +4, —6, —13; in the second case, +40, +18, +6, —2, —9. Regarding these as two sets, each consisting of five independent and equally precise observations, we find that they indicate a change of $3.^s8$, with a probable error of $0.^s6$. It, therefore, seems reasonable to hope that in the final reduction, in which proper weight will be assigned to each observation, the time of each eclipse will be determined with a probable error of less than a second. The probable error in observations of the customary kind was found by M. Glasenapp, some years ago, to be between nine and ten seconds. If further experience confirms the expectations now entertained with regard to the photometric method, the eclipses of Jupiter's satellites may again come into use as a means of determining the longitudes of remote stations. The eclipses of the three outer satellites furnish nearly as good results as those of the first, since the greater number of observations attainable compensates a considerable extent for the less rapid variation in brightness.

A new photometer, frequently used in the more recent of these observations, is mentioned under the heading "Variable Stars."

Planetary Nebulæ. — The observations of these objects described in my last report are now nearly completed. Four sets of measures of the light of each nebula are made, the work on each not being confined to one night, and being conducted by different observers, so that the results may be more trustworthy. The spectra of the nebulæ are also observed through a direct-vision prism placed between the object-glass and the eyepiece of the telescope. The planetary nebulæ retain their shape under these circumstances, which obviously indicates that their light is mainly monochromatic. The presence of a continuous spectrum, too faint for observation by a spectroscope of the usual form, is also frequently detected by the method above described.

The difference in the appearance of monochromatic objects and of ordinary stars is so marked when thus examined as to offer a promising method of discovering some small bright nebulæ, which would appear as stars with an ordinary eyepiece. A region where planetary nebulæ were known to be comparatively frequent was accordingly examined with the prism, and three objects of the expected kind were found. Their positions for 1880 are as follows: R. A. $18^h 4^m 19^s$, Dec. —28° 12′; R. A. $18^h 14^m 23^s$, Dec. — 26° 53′; R. A. $18^h 25^m 10^s$, Dec. —25° 13′.

A systematic search was accordingly undertaken, and has been completed for about six hundred square degrees. A more rapid survey of the whole heavens has also been begun with the Bowditch Comet-seeker. About an eighth of the visible heavens has thus far been explored. No additional monochromatic objects have been found; but two of the stars examined probably belong to Secchi's fourth type, of which only about fifty were previously known. Their positions for 1880 are in R. A. $19^h 55^m 16^s$, Dec. —28° 3′; R. A. $19^h 59^m 35^s$, Dec. —27° 34′. R Aquarii seems to be of the same class. Its place for 1880 is in R. A. $23^h 37^m 37^s$, Dec. —15° 57′.

The most remarkable discovery, however, is that the spectrum of the star Oeltzen 17681 (the place of which for 1880 is in R. A. $18^h 1^m 17^s$, Dec. —21° 1′), possesses a peculiar character. The light of this star is principally concentrated in two points of the spectrum, one in the blue, the other in the yellow, a little more refrangible than the D line. A faint, continuous spectrum is also seen.

By sweeping the telescope over the region, the stars may be examined very rapidly. Over a hundred thousand spectra have already been viewed in this way, and it is expected that by the end of the next year the number observed will exceed half a million.

Variable Stars. — Last summer a remarkable variable star was discovered by M. Ceraski of the Moscow Observatory. This star belongs to the Algol type, of which only five others are as yet known. Its period was announced as about ten days. Dr. Schmidt showed that this time should be divided by two, and gave the period as a little less than five days. Observations made at this Observatory showed that the period should be again divided by two, so that the true period is only two days and a half. The star has also been watched to see that no further subdivision will be made. Photometric measures have been made of the light of the comparison stars, and preparations are now in progress for determining the light curve of the variable photometrically.

The new star in Cygnus was found by Lord Lindsay to consist of monochromatic light, or apparently to have changed into a planetary nebula. This object has now diminished greatly in light, and appears to have lost this peculiarity, and to give a continuous spectrum like that of an ordinary star. Regarding it as a nebula, we seem to have, in this case at least, undoubted evidence of variability.

A new photometer has been constructed for the comparison of stars moderately near each other, but too distant to be brought into the same field by any of the photometers previously in use. The polarized images of the two stars are brought to equality by turning a Nicol prism, and both images are seen under the same conditions. The range of positions in which the double-image prism may be placed is greater in this than in previous photometers made on the same general principle. The instrument has hitherto been used, when attached to the equatorial, for the observation of eclipses of Jupiter's satellites. Its most extensive employment has been in comparisons of β with ω *Persei*, for which purpose it is provided with a small object-glass, and mounted as a separate instrument. The results of these comparisons are, in general, remarkably accordant, and seem to promise a determination of the light curve of β *Persei* with increased precision. Three observers take part in the work, each taking in turn three sets of four settings each, reversing the images in the middle of each set. The average deviation of the sets amounts only to about 0.06 magnitudes. Accordingly, while photometric observations in general give results somewhat less accordant than those obtained by the naked eye under favorable circumstances, this instrument appears to surpass the unaided eye in precision, without losing the advantage common to all good photometers of supplying results independent of each other and reducible to a definite standard.

Miscellaneous. — The places of Hartwig's comet (1880 *d*), and of Iphigenia (112), have been observed by Mr. Wendell. The four first asteroids — Ceres, Pallas, Juno, and Vesta — have likewise been photometrically observed.

The investigation of suitable methods for the detection of stars having a considerable parallax or proper motion, which was proposed by Mr. Searle, has been carried on by him, with the aid of Mr. Wendell as in the previous year, during the few hours, generally towards the end of the night, which could be made available for the purpose; and will perhaps be continued, as opportunities may occur, with apparatus improved in accordance with the indications afforded by the observations already made.

Meridian Circle. — The present Report covers the period from September 24, 1879, to November 1, 1880. During this time observations have been made on 277 days. This number of days is distributed by months as follows: —

	Month.	No. Days Observed.		Month.	No. Days Observed.
1879.	September, . . .	7	1880.	April	27
,,	October	26	,,	May	27
,,	November, . . .	18	,,	June	28
,,	December, . . .	23	,,	July	22
1880.	January	2	,,	August . . .	21
,,	February	0	,,	September . .	26
,,	March	23	,,	October . . .	27

During the present year, work with the Meridian Circle has been for the most part limited to the continuation of the observations for the determination of the absolute co-ordinates of the selected list of 109 fundamental stars. The only miscellaneous work, has been a series of observations for the determination of the difference of longitude between this Observatory and the Winchester Observatory of Yale College.

The series of observations which was begun February 15, 1879, was completed January 3, 1880.

Before the commencement of the series for the current year, the following instrumental changes were made: —

(*a*) The Standard Clock, Frodsham, No. 1327, was removed from its exposed position in the East Computing Room to the pier formerly occupied by the Howard Clock in the Clock-room of the Time Service.

(*b*) In order to furnish the means of measuring the variation of the instrumental constants during the interval from one culmination of Polaris to the next, Messrs. Alvan Clark & Sons were employed to construct a collimator of long focus. The marble cap-stone of the south collimator pier was removed, and four upright rods were inserted in the brick pier, by which the bed-plate carrying the Y's of the collimator-tube were firmly secured. The object-glass of the new collimator, which has a focus of 206 feet, was set in a frame which was securely fastened to the under side of the bed-plate holding the object-glass of the regular collimator. An opening through the pier and the wall of the building allows the free passage of light.

The experience of 1879 has shown that it is impossible for one observer to carry on the regular system of observations, and at the same time make, in a systematic way, the requisite number of observations for the investigation of the differential refraction by means of a large and miscellaneous list of stars. The observations of this class made during the present year were therefore limited to a few stars observed, as nearly as possible, at successive culminations.

It has been found impracticable to limit the observations to stars which have nearly the same declination as the sun, and at the same time to obtain an equal number of observations at opposite seasons of the year. Hence, during the present year, the entire working-list has been arranged in the order of right ascension. The advantage gained by making the observations differential with respect to the sun will be secured in their reduction.

Inasmuch as the report of the last year closed in September, the tabular statement of the observations for the entire series is included in the series for 1880.

The limiting dates for the different classes of observations are as follows: —

Entire Series I. extends from February 15, 1879, to January 2, 1880.
Entire Series II. extends from February 29, 1880, to November 1, 1880.
Series at Vernal Equinox extends from February 15, 1880, to April 27, 1880.
Series at Autumnal Equinox extends from August 15, 1880, to November 1, 1880.
Series at North Solstice extends from June 6, 1880, to July 6, 1880.
Series at South Solstice extends from December 7, 1880, to January 4, 1880.

	Polaris. No. Obs.			Sun. No. Obs.					Observations for Refraction.			Fundamental Stars.
	U. C.	L. C.	Total.	Vernal Eq.	Autumn Eq.	North Solstice.	South Solstice.	Total.	No. Stars.	No. Obs. U. C.	No. Obs. L. C.	No. Obs.
1879.	102	112	214	36	42	18	10	143	62	232	143	1744
1880.	80	103	183	33	42	24		131	10	131	70	1760

Of the entire number of observations of fundamental stars made during the present year, 1,010 were made previous to August 15; and 750 observations of the same stars were made between August 15 and November 1. At the conclusion of the series in January, these numbers will be nearly equal.

The number of observations between noon and midnight is nearly equal to that between midnight and the following noon.

Reductions. — The chronograph sheets for 1879–80 have been read off to August of the current year. Beyond this but little work has been done towards the reduction of the observations.

Since the completion of Vol. XII. the time of the computing force has been devoted exclusively to the reduction of the zone observations. In order to give a symmetrical character to the entire series of zone observations, it was considered better to make the instrumental constants and clock errors depend directly upon the places of the fundamental stars given in Publication XIV. of the Astronomische Gesellschaft. The labor of recomputation for the years 1871, 1872, 1874 and 1875 has not been very great.

The present state of the zone reductions is as follows: —

(*a*) The means of the right-ascension wires, of the declination wires, and of the circle-readings, have been taken in duplicate for the entire series.

(*b*) The instrumental errors in right-ascension, and the clock errors, have been recomputed from May, 1872, to January, 1879.

(*c*) The declination constants have been recomputed for the same period except for the years 1876 and 1877.

(*d*) Considerable progress has been made with the reduction of the fundamental stars between November 10, 1870, and May, 1872.

The investigation of the variability of the flexure of the telescope has been so far completed that it is safe to say that for the zenith distance 53° the value of the flexure for January of any year is about 0.″6 greater than for July of the same year. This variability was suspected as early as 1876; but it was impossible to determine at that time whether it might not be due either to the refraction constants employed, or to the systematic errors of the provisional system of fundamental stars. Beginning with September, 1878, observations for flexure have been made with the collimators whenever the conditions for its determination have been favorable. The agreement of the values derived in this way with those derived from the new system of fundamental stars seems to indicate that the Pulkowa constants for refraction nearly satisfy observations made under the atmospheric conditions common in this latitude.

Meridian Photometer. — Much progress has been made with the undertaking announced in my last report of measuring the light of all the stars visible to the naked eye between the north pole and —30°. The photometer consists of a transit instrument in which polarized images of the star to be measured and of the pole-star are placed side by side in the field, and brought to equality by turning a Nicol prism inserted in the eye-piece. The instrument is so constructed that the two objects are viewed under precisely the same conditions, with the same magnifying power, the same aperture, the same background, and the same emergent pencil. Moreover, their positions are reversed during each observation. The observer remains in comparative darkness and confines his attention to the settings, all the readings of circles and the recording being done by an assistant. A large number of preliminary measures were made, during which various sources of error were detected. These were finally eliminated, and the first zone was taken on Oct. 25, 1879. Owing to bad weather and other causes, only twenty zones were taken before December. Since then two or three zones of about an hour each have been taken by different observers on almost every clear evening. Before Nov. 1, 1880, 298 zones were taken on 137 nights. The working-list contains about four thousand stars, each of which is to be observed on three different nights by different observers. Four settings are made each night. To determine the atmospheric absorption, a hundred circumpolar stars are observed at their upper and lower culminations. Each of these stars will be observed on about ten or twelve nights. The stars of the first and second magnitude will also be observed on about twelve nights. Except in a few of the early zones, two images of the pole-star are compared at the beginning, middle, and end of each zone, thus eliminating differences in the two objectives and prisms. The number of separate settings is as follows: 30,076 of ordinary stars, 2,996 upper culminations, 3,168 lower culminations, 1,268 of bright stars, and 2,848 of the pole-star. Total, 40,356. Besides these, many measures have been made of the brighter planets, of Vesta, and of the brighter variables and their comparison stars.

More than half of the work is now done, and it is probable that the observations will be completed during next October, unless the weather is very unfavorable. It is possible, however, that additional observations will be made of the brighter stars and of the variables, and the work thus extended through another year. In this case the total number of settings will doubtless exceed one hundred thousand. The average difference in the three measures of the pole-star taken in each zone is somewhat less than 0.08 magnitudes. The probable error in the mean of the three measures of a star is also about 0.08 magnitudes. When the three measures differ so much that the probable error exceeds 0.2, another observation is taken, and this is repeated until the error is reduced to 0.2, or until one of the observations is shown to be erroneous. Although the reduction of a single observation is very simple, yet the great number taken renders the clerical work very laborious, the manuscript already filling about seven reams of letter paper.

Time-Signals. — The distribution of time-signals from the Observatory has been efficiently maintained during the year by Mr. F. Waldo, the assistant in charge of this service. The error of the signals at 10 A.M. has very seldom exceeded one-tenth of a second, as determined by comparison with the standard sidereal clock. The clock-room, built in the cellar of the west wing of the Observatory, continues to give satisfaction. The extreme variation in its temperature during the year was 13.2 degrees Fahrenheit, and the variation from week to week is only about four degrees.

The Observatory and the Waltham Watch Factory are in telegraphic communication; and an arrangement has been made with the Watch Company which permits the use of an excellent clock at the factory for comparison with the clocks of the Observatory. This is chiefly serviceable as an additional security in the observations made with the meridian circle, but it may be of occasional use also in the distribution of time-signals in case of accident or during a long continuance of cloudy weather.

The signals sent from this Observatory are used in New York, in connection with those of the United States Naval Observatory and of the Allegheny Observatory for the regulation of the New York time-service. This Observatory receives no payment for the assistance thus rendered.

The time-ball in Boston has been dropped at noon with great regularity and precision, owing largely to the skill and care, and especially to the experience, of Mr. Purssell of the United States Signal Service, who is in charge of the ball. On 355 days, the ball was dropped exactly at noon, and on four other days at five minutes past noon, according to the rule adopted; on four days it was not dropped, — leaving only three cases of inaccuracy of dropping. From May 1 to Nov. 1, 1880, no failure has occurred; and in only one case has the descent of the ball been postponed five minutes; on one other occasion it was dropped at noon by hand, instead of by telegraph.

The telegraph lines and batteries have continued in charge of Messrs. Stearns and George, whose care and watchfulness have largely contributed to the efficiency of the work.

Publication. — The second part of Volume XI. of the Annals of the Observatory has been completed and distributed during the past year. It contains a discussion of a part of 25,000 photometric observations made with the large equatorial in 1877, 1878, and 1879. This discussion relates chiefly to the fainter objects observed, such as the satellites of planets and minute stars situated near brighter ones. No photometric observations of most of these objects were previously in existence, and these must accordingly have a considerable value, although they cannot be expected to be as accurate as the observations of brighter objects, made with photometers of a different kind, and discussed in Part I. of the same volume. The faint objects should, if possible, be reobserved by some method wholly different from that first employed, and this work will probably be undertaken here at some future time.

Volume XII., which contains the results of observations made in 1874 and 1875 by Professor W. A. Rogers with the Meridian Circle, has also been completed and distributed. This volume includes a discussion of the proper motion of 618 stars, and a comparison of their places as found here and at other observatories. The values of the probable errors show that the work compares favorably with the best done elsewhere. The list of stars is substantially the same as that of Volume X. In that volume the times of transit over the separate wires were given in full; but in Volume XII. only the means have been published; and the expense of publication makes it probable that still further abridgment will be necessary in future volumes of the same class.

The following publications have also been made by officers of the Observatory: —

On the Present State of the Question of Standards of Length. By Wm. A. Rogers. Proc. Amer. Acad., xv. 273.

On Tolles' Interior Illuminator for Opaque Objects. By Wm. A. Rogers. Journ. Roy. Micros. Soc., iii. 754.

Observations of Comet *c*, 1879 (Swift), made with the 15-inch Equatorial of the Harvard College Observatory. O. C. Wendell. Astron. Nach., xcvi. 21, No. 2282. Observations on sixteen nights.

Observations of the Satellites of Mars made at the Harvard College Observatory. Edward C. Pickering and O. C. Wendell. Astron. Nach., xcvii. 115, 145. Nos. 2312, 2314. Contains the results of 1,348 observations.

Dimensions of the Fixed Stars with Especial Reference to Binaries and Variables of the Algol Type. Edward C. Pickering. Proc. Amer. Acad., xvi. 1. pp. 37. Contains a discussion of the conclusions that might be derived if all stars had equal intrinsic brightness; also determines the orbit which a dark satellite must have to produce the observed variations in light of *β Persei.*

New Planetary Nebulæ. Edward C. Pickering. Amer. Journ. of Science, xx. 303.

The following papers were read by Professor Rogers before the American Association, and will appear in their forthcoming volume of Proceedings: —

On the Progress made at the Observatory of Harvard College in the Determination of the Absolute Co-ordinates of 109 Fundamental Stars.

On a Simple and Expeditious Method of Investigating all the Division Errors of a Meridian Circle.

On the Systematic Errors of the Greenwich Right Ascensions of Southern Stars observed between 1816 and 1831.

On a Preliminary Determination of the Equation between the British Imperial Standard Yard and the Metre of the Archives.

Besides some shorter notices, the following reviews of the Annals have been published: Vol. IX., by Mr. Th. Wolff, in Vierteljahr. der Astron. Gesell., xv. 193; Vol. XI., Part I., by Mr. E. Lindemann, Vierteljahr. der Astron. Gesell., xv. 208. Vol. XI. has also been reviewed in Nature, xxi. 23; Observatory, iii. 387, 515; and the Astronomical Register, xvii. 290, xviii. 110.

A circular inquiring to what extent the series of Annals of this Observatory was complete as far as Volume XI. inclusive, was prepared last winter, and over two hundred copies of it were sent in February to the institutions and to some of the astronomers among whom our publications are distributed. At the time of the distribution of Volume XII., in July, the deficiencies reported in answer to the circular were supplied so far as the stock of the older volumes would permit; and a second copy of the circular was sent to each library from which no reply to the first copy had been received. From the reports which have thus far been made it appears that fifty-nine sets of the Annals were already complete; and this number has been increased to eighty-nine by the recent distribution. Forty-six sets were also partially completed, and notice sent of the scarcity of the volumes not supplied. From thirty-five institutions no reply to the circular has as yet been received. The volumes for which the demand relatively to the stock on hand is greatest are: II. Part I. (observations of Saturn), III. (Comet of 1858), and V. (Nebula in Orion). These can be supplied only in exceptional cases. Any duplicate copies will be thankfully received, and will be used in completing broken sets. The following statement shows that few copies remain of some other early volumes, duplicates of which would also be welcome: —

Vol. I. Part I. 242, Part II. 98; Vol. II. Part I. 39, Part II. 45; Vol. III. 43; Vol. IV. Part I. 22, Part II. 157; Vol. V. 39; Vol. VI. 191; Vol. VII. 124; Vol. VIII. 30; Vol. IX. 300; Vol. X. 115; Vol. XI. Part I. 189, Part II. 206; Vol. XII. 180.

A new edition of Vol. VIII. was published by Messrs. Ginn & Heath; but a large portion of it was destroyed by fire some months ago, and the remainder was purchased by the Observatory in order to complete sets.

A re-examination has been made of the equatorial observations taken in 1866–76. A second reduction of the measurements of double stars is now nearly complete. The observations of nebulæ and of occultations are also nearly ready for the press. The observations of asteroids and comets have in most cases lost their value; but, as they may be much needed in special cases, it is proposed to publish an index to them, so that any which are wanted can be furnished on application to this Observatory.

A beginning has been made in the reduction of the meteorological observations from 1840 to 1880. Owing to their great bulk, it is probable that only the monthly means will be published. These, with the Meridian Circle observations, the recent photometric observations of the large telescope, the work with the Meridian Photometer, and the observations of Jupiter's satellites, will fill at least six volumes, which are in a more or less advanced state of preparation for publication.

Library. — Notwithstanding the additional shelves placed in the Library, more room is now much needed, and it will probably be necessary soon to devote the room opposite to library purposes. Some binding has been done, especially in collecting the pamphlets, but much more is required. One or two hundred volumes could be bound to advantage. The press of other work has also prevented cataloguing the later additions to the Library, and marking the books so as to define their precise location. The Library, however, is not yet so large as to render this omission a serious inconvenience.

Buildings, Grounds, &c. — Various improvements have been made in the west wing of the Observatory. The wooden pier of the west Equatorial had become somewhat unsteady; it obstructed and darkened the entry through the building, and was a source of much danger in case of fire. The entry was accordingly carried through it, over a structure of brick in the basement, where a pier suitable for a clock has been placed. Additional storage room for volumes of the Annals was attained by this alteration. Hard-pine floors were laid in the entries and in the Library. The entries were painted and the upper story repapered. A handsome carpet has also been purchased for the Computing Room in the east wing.

The lower end of the sunken road, formerly opening on Concord Avenue, has been filled up, and the appearance of this part of the grounds has been greatly improved. Another important improvement has been made by regrading and sowing with grass-seed the portion of the grounds near Madison Street.

Last spring an unusually favorable opportunity offered itself to Professor Rogers to procure copies of the standard yard and metre, and to determine the relation between them. He accordingly made a brief visit to France and England for this purpose, and collected the material for what promises to be a valuable contribution to this subject.

It is my painful duty to announce the death of Mr. Joseph F. McCormack, who aided in the work of the Observatory from 1872 to 1880. He was a faithful and conscientious assistant, and attained great skill in his special work, that of reading the microscopes of the Meridian Circle. He died of typhoid fever on Feb. 2, 1880, at the age of twenty-five years and six months.

The principal want of the Observatory at the present time is means for the publication of its Annals. The large number of volumes (Vols. IV. Part II., VIII., IX., X., XI. Parts I. and II., and XII.) issued during the past five years has exhausted the accumulated interest of the Sturgis Fund; only one more volume can be paid for at present from the Quincy Fund; and no other funds are especially intended to defray the expenses of publication. A part of the annual subscriptions might be used for printing; but this seems unadvisable while the whole can be so usefully and economically employed in providing additional assistance for carrying on and reducing the work of the Equatorial and other instruments.

The cost of each volume will be about two thousand dollars, or where the two parts are published separately, about a thousand dollars for each part. Some volumes, especially the results of the zone observations and of the Meridian Photometer, are likely to be standard works of reference for many years. It is hoped that persons may be found willing to further the cause of astronomical science by contributing to this object.

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1880–81.

To the President of the University:

Sir, — The present condition of the Harvard College Observatory furnishes a test of an opinion expressed in some of its recent annual reports, namely, that any addition to the resources of a scientific institution already supplied with the funds needed to keep it in working order will prove an advantageous investment. Such a sum is directly applicable to the extension of scientific inquiry. A similar gift to establish a new institution, or to support a feeble one, will be largely consumed in the mere preparation for such inquiry, and the head of the institution must spend much of his time in routine work, even if he is not required to devote a large part of his energies to teaching, as well as to research.

The proper division of labor, and the continuous use of apparatus, are advantages as important in science as in the arts. These advantages are possessed by a liberally endowed observatory as they are by the factory of a rich proprietor, who can afford any immediate expense required to secure the most abundant returns. It seldom happens that the endowment permits the use of the instruments to their full capacity. Until this point is reached, great results may always be expected from a slight increase of income.

The subscription raised in 1878 for the support of the Observatory for five years has given it for that time a much improved position for conducting researches. Many of the contributors to the fund paid their subscriptions in full at the outset, and the Observatory thus acquired a large balance to the credit of its account with the University, which will of course progressively diminish until the five years have expired.

One of the most important advantages resulting to the Observatory from this temporary enlargement of its resources consists in the increased number of its assistants, which is now sufficient to allow the work of each to be more advantageously directed than was previously possible.

The observations with the large equatorial and meridian photometer are made by Mr. Searle, Mr. Wendell, and myself. Messrs. Cutler and Eaton assist in recording these observations and in their reduction. Miss Farrar and Mrs. Fleming also take part in the reductions. The meridian circle remains in the charge of Professor Rogers, who is aided in the observations by Mr. Brown, and in their reduction also by Mrs. Rogers and by Misses Saunders, Bond, and Winlock. The time-signals are in charge of Mr. Edmands, assisted by Mr. Chandler. These gentlemen and Mr. Howard are making the naked-eye observations of northern stars. The meteorological observations are ordinarily made by Mr. Searle, who also has charge of the accounts, correspondence, &c., and has devoted much time to work connected with the revision and publication of the equatorial observations. The compilation of the bibliography of the variable stars, and the computation of cometary orbits as noted below, are conducted by Mr. Chandler.

Three instruments, the equatorial, meridian circle, and meridian photometer, have been kept actively at work during the past year. The last of these instruments has proved so satisfactory that a large one is being constructed to carry on observations of stars too faint for the present instrument. The new photometer will have object-glasses four inches in diameter, and will be capable of measuring any star brighter than the tenth magnitude. It is expected that such measurements will form a part of the permanent routine work of the Observatory. The relation of a meridian photometer to other photometers resembles that of a transit instrument to a sextant. There are the same advantages of rapidity, ease of reduction, and probably of precision. On the completion of the new photometer we shall have the same advantages for measuring the light of any star that an observer would of finding its position if he possessed the only transit instrument in existence. It is hoped that the use of this instrument will become more general when its advantages are appreciated. I understand that a distinguished German astronomer is planning a photometer for similar work, and at his request a description of the instrument used here has been forwarded to him.

The work of these various instruments will now be considered. That of the large telescope may be classified as below, with reference to the principal objects observed.

Eclipses of Jupiter's Satellites. — One hundred and fifty-three of these eclipses have been observed photometrically, sixty-four during the past year. One improvement has been introduced by which the number of settings may be nearly doubled. A single observer can make but three settings a minute, or one in twenty seconds. With an assistant to record, the time is reduced to about nine seconds. This time has been reduced to five seconds by the employment of two assistants, one of whom reads the photometer circle, while the other records and observes the time by the chronometer. As the observer does not remove his eye from the eye-piece, it is probable that the accuracy of the observations will be increased, and the satellite followed nearer to the point of disappearance.

Objects having Singular Spectra. — The search for these objects has been much interrupted by the pressure of other work. Only perfectly clear nights when the moon is absent are available, and these rarely occur at certain seasons of the year. The general survey of the heavens with a telescope of four inches aperture has been completed from twenty to twelve hours of right ascension. The observations during the summer on the remaining eight hours were so much interrupted by the long twilight and other causes that it was deemed best to reserve this work for another season. The most important result of this search has been the discovery of the peculiar spectrum of the star Ll. 13412. Three bright lines were found having wave-lengths of 545, 486, and 466 millionths of a millimeter. The second of these lines probably coincides with the F line of hydrogen. The other two were unexplained until Dr. Konkoly, in "The Observatory," IV. 257, described the spectrum of Comet 1881 III. (the Great Comet), as containing the five lines 560, 545, 515, 472, and 468. Three of these, the first, third, and fourth, are the usual cometary lines;

the other two appear to be coincident with the lines of Ll. 13412. Accordingly, while other comets have a spectrum identical with that of the stars of Secchi's fourth type, and apparently largely composed of carbon, this comet contains a substance as yet unknown, which one star only is as yet known to contain. The bright-line stars in *Cygnus* and in *Sagittarius* also give the line 467, but differ in the position of the other lines.

Another interesting discovery is that the star *L^2Puppis* has a banded spectrum. This star is more than forty-four degrees south of the equator, and at the time of observation was less than two degrees above the horizon.

Two stars were found, one in *Puppis*, the other in *Ursa Minor*, which from their color and spectrum were at once thought to be variables of long period. These predictions were verified by observation, and a very rapid method of discovering variable stars is thus suggested. An announcement of the last of these discoveries was telegraphed to the Astronomische Gesellschaft as an example of the cipher code referred to below.

The spectra of all the stars north of —40°, marked as red or colored in the Uranometria Argentina, have been examined in the large telescope. In most of them no peculiarity of spectrum could be detected. From the remainder, and from some miscellaneous sweeping for such objects, a list of about eighty stars having banded spectra has been compiled and published.

Variable Stars. — The photometric study of the stars *β Persei* and DM. 81° 25, proposed in my last report, has been carried out. The number of comparisons made of *β* and *ω Persei* was 2,748, six hundred during a single night. On this occasion the observations were continued almost without intermission from a quarter of seven in the evening to half past three in the morning. In like manner, 3,276 comparisons of DM. 81° 25 and 26 were made on five evenings. Nine hundred settings were obtained during one night. The probable error of a single minimum determined in this way is only about 1.3 minutes.

Comets. — This Observatory has taken an important part in the early distribution of circulars relating to the comets recently discovered, by defraying the cost of telegrams, and by furnishing the necessary observations and computations. In co-operation with the Dun Echt Observatory and the Science Observer, circulars have been distributed in Europe and America, giving an early announcement of the elements and ephemerides of the five new comets discovered in the first ten months of 1881. The average interval between the time of announcement of the comet and the issue of the circular has been less than a week. The interval between the last of the observations needed to determine the orbit and the time of telegraphing the elements to Europe has been less than two days. The computations have been generally made by Mr. Chandler, who has not hesitated, whenever necessary, to continue them through the entire night. No important error has occurred in their telegraphic transmission to Europe, by means of the ingenious cipher code devised by Messrs. Chandler and Ritchie. These preliminary orbits proved sufficiently accurate for the purpose for which they were intended. That of the Great Comet of the year (Comet 1881 III.), was published within four days of the first appearance of the comet in the northern heavens, and agreed more nearly with observation than any other published elsewhere for some time. This agreement was due to the use of an early observation made at Rio. Barnard's Comet was not found in Europe until the publication of the ephemeris computed here. Denning's Comet was early suspected by Mr. Chandler to be periodic. Elliptic elements were computed by him; but a later mail showed that he had been preceded by Dr. Schulhof of Paris in this work.

The use of the large telescope in the observation of comets has not, in general, been allowed to interfere with the other work of this instrument, except when early observations were needed for the determination of their obits. Almost all of the observations were made by Mr. Wendell, many of them late in the night, when the telescope was not otherwise occupied. Comet 1880 IV. was observed on twenty-nine nights; Comet 1881 II., on two; Comet 1881 III., on forty-three; Comet 1881 IV., on fifteen; Barnard's Comet 1881, on ten; and Denning's Comet 1881, on eight.

Some miscellaneous measurements have also been made of these comets, particularly of Comet 1881 III. The form of this comet's tail was measured, and the brightness of portions of it at various distances from the head.

Meridian Circle. — During the past year observations have been made on 250 days. This number is distributed by months as follows: —

	Month.	No. Days.		Month.	No. Days.
1880.	November . . .	26	1881.	May	20
1880.	December . . .	21	"	June	18
1881.	January	24	"	July	22
"	February . . .	18	"	August	12
"	March	17	"	September . . .	23
"	April	24	"	October	25

The whole number of observations made during the past year is as follows: —

		No. Obs.	Total No. Obs.
Polaris.	Upper Culmination	122 . . .	
Polaris.	Lower Culmination	110 . . .	232
Sun.	Vernal Equinox	31 . . .	
	Autumnal Equinox	45 . . .	
	North Solstice	13 . . .	
	South Solstice	15 . . .	158
	Fundamental Stars		1999
Polar Stars.	Upper Culmination	293 . . .	
	Lower Culmination	170 . . .	463
Miscellaneous	. . . .		350

The observations for the determination of the horizontal flexure by means of the collimators have been continued throughout the entire year as often as the atmospheric conditions have been favorable. The whole number of observations is fifty-eight. It was stated in the last report that the horizontal flexure for January of any year had been found to be about 0″.6 greater than for July of the same year. Since that time the values of this function derived from the fundamental stars observed have been computed for the years 1876 and 1877. We have now, therefore, sufficient data to determine the reality of this apparent variation. The values given below represent the difference between the value of the correction described as horizontal flexure for the mean of the months of January and December of any year and for the month of July of the same year both from the fundamental stars and from the collimators.

From the Fundamental Stars.		From the Collimators.	
$\frac{\text{Jan.}+\text{Dec.}}{2}$	— July ΔR_4. ″	Jan.	— July ΔR_4. ″
1872	+0.64	1879	+0.73
1873	+0.39	1880	+0.56
1874	+1.09	1881	+0.48
1875	+0.73		
1876	+0.14		
1877	+0.71		
1878	+0.62		
Means	+0.62		+0.59

The action of temperature upon the screws by which the two halves of the tube of the telescope are joined to the cube of the circle is suggested as the probable cause of this difference. Observations with the long collimator for the determination of the variation of the instrumental constants of the instrument have been continued throughout the year. For the most part there are two series during each day on which stars have been observed. During the autumn and winter, the image of the concentric rings, or the focus of the collimator, remains remarkably steady; but during the summer, it has been found necessary to limit the observations to the evening and to the early morning hours. As a further check upon the variability of the index-error of the circle, some experiments were made with the reserve level of the Russian transit; this method, however, proved unsatisfactory. A level of the form invented by Mr. John Clark was ordered of Fauth & Co., and was mounted upon the cube of the telescope in May. The use of this instrument has been limited to the determination of the variability of the level of the telescope and of the index-error of the circle. A definitive opinion of the value of this method of detecting changes in the position of the zero of the circle must be deferred till the value of the index-error has been derived from the observations of Polaris. According to present indications the level gives somewhat better results than the long collimator. At present the observations are arranged for the detection of changes occurring between the morning and evening hours.

A decided improvement in the performance of the Standard Clock, Frodsham No. 1327, has been maintained since its removal to the cellar of the building, as is shown below in the account of the Time Service. The extreme variation of the thermometer placed within the room and read through a glass window from the outside has been 8°. Comparisons of this clock with the mean-time clock at Waltham have been continued as before by means of the line of telegraph erected for the purpose.

The investigation of the errors of the fixed circle of the telescope for each degree was completed in August. A metal plate having an arc of 15° subdivided to 5′ was used for the investigation. It was attached to the frame which carries the microscopes opposite the circle to be examined. The frame proved to be capable of revolution with no sensible disturbance of the focus of the microscopes. Each 15° of the fixed circle was compared with the constant arc upon the plate. Two series, one in May and the other in August, show a good agreement. The maximum error of any space was found to be about $1''.4$, and the accumulated systematic error for 180° does not exceed $1''.3$. The errors of the single degrees were found by comparing each degree with the first degree of the metal plate. From the provisional reductions it appears that the accidental errors of division rarely reach $1''$ and that with two or three exceptions they never exceed $1''.3$. The investigation is to be completed by an examination of each space of $5'$.

Observations of certain stars were made at the request of Professor Davidson of the United States Coast Survey, of Professor Hall of the Naval Observatory, and of Captain Tupman of the Greenwich Observatory. Two observations were made of Comet 1881 III., and a special series of 280 observations was made for the purpose of ascertaining whether the telescope moves in a vertical plane during its revolution.

The chronograph sheets for 1880–81 have been read off to July of the current year. Since the last report, considerable progress has been made in the reduction of the zone observations. In the preliminary reductions of the fundamental stars, the observations of a few stars were found to indicate persistently a disagreement with the fundamental positions of Publication XIV.

By comparing the separate values of $(\Delta T+m)$ and of the equator-point correction for each date with the mean values of these functions for the same date, a list of stars showing substantially the same discordances from year to year was made out. From this list twelve stars in right ascension and forty stars in declination were selected for special examination. A list of the resulting corrections to the positions in Publication XIV. was submitted to Professor Auwers, with a request for instructions in regard to the proper course to be pursued in this case. He has subsequently authorized, on behalf of the Council of the Astronomische Gesellschaft, the use of the provisional corrections already found. The actual determination of the definitive values of $(\Delta T+m)$ and of the equator-point correction has been unavoidably delayed by this inquiry.

The right ascension constants have now been determined for the entire series from 1870 to 1879, and the declination constants have also been found for the same time, except for the year 1871–72. The computation for this interval is nearly completed.

The entire number of dates, for which the constants have been determined, is 1,263. The tabular reductions to apparent place and the refractions have been completed for the entire series of zone observations. The reductions have been made for intervals of twenty minutes in right ascension and two degrees in declination. The whole number of days for which these computations have been made is 633, and the number of individual reductions is about 12,000.

Meridian Photometer. — The work originally proposed for this instrument of measuring on three nights the light of each of the naked-eye stars visible in this latitude was essentially completed August 25, 1881. The observations will be continued during another year, as the necessary delay for reduction and publication will not thereby be greatly increased. Of the four thousand stars in our catalogue, about fifteen hundred have been selected for re-observation on three nights each. We shall thus obtain at least six observations of these stars, which include all those brighter than the fourth magnitude, all those used in the principal nautical almanacs as standards, and all those of which the first measures proved discordant. About seventy-six thousand measures have been made in all; thirty-six thousand since November 1, 1880.

From a discussion of the upper and lower culminations of a hundred circumpolar stars, the law of atmospheric absorption has been deduced, and the corresponding correction for each of the stars observed determined. All the readings have been reduced to magnitudes, corrected for the difference in transparency of the prisms, the mean taken when the stars are completed, the residuals derived, and the probable error deduced. This work has also been in a great measure checked and entered in the sheets of copy ready for publication.

A comparison of the photometric observations with those made by the naked eye is much to be desired. The Uranometria Argentina furnishes the means of doing this with the southern stars, but extends only to 10° north. Accordingly, all the stars in the Atlas Coelestis Novus of Heis north of the equator, and brighter than the sixth magnitude inclusive, are being measured by the eye, aided, when necessary, by an opera-glass. Each star is to be measured by three observers, who are to compare it with two stars in the vicinity of the pole, one being a little brighter, the other a little fainter. The interval between the two is supposed to be divided into ten parts, and the brightness of the star to be measured is estimated in terms of this interval. The standard stars, one hundred and fifty-seven in number, include all stars brighter than the second magnitude, and those between 60° and 75° north, which are used in determining the atmospheric absorption. The total number of comparisons required for this work is about nine thousand, of which nearly a quarter have already been made.

Time-Signals. — The distribution of time-signals continued in charge of Mr. F. Waldo until June 1, and since then Mr. Edmands has assumed their care. Special attention is now given to keeping the error always small, instead of reducing it to zero at 10 A. M. By graphical methods, the accuracy of the determination of the error during long periods of cloudy weather has been much increased. It is believed that the error rarely exceeds two tenths of a second in clear weather, and four tenths when cloudy, and that the error seldom changes more than two tenths of a second from one day to the next.

In July, the mean-time clock, Bond 394, stopped, after sending the signals continuously for four years. It was kept in use, however, till October, when it was dismounted and thoroughly repaired. Meanwhile, from October 7 to October 21, the time-signals were sent by the clock of Messrs. W. Bond & Son, in Boston. It is hoped that hereafter it will not be necessary to take this course, as the sufficiently exact regulation of a clock so far from the Observatory proved to be a troublesome and laborious undertaking. In August, the standard sidereal clock, Frodsham 1327, was cleaned and removed to the new brick vault under the west Equatorial. For a period of twenty-five days, beginning August 30, during which it was left wholly undisturbed, its performance was remarkable both for the uniformity and minuteness of its rate. Its error did not vary two tenths of a second on the thirty-two occasions on which it was compared with the stars.

Various ingenious devices have been adopted by Mr. Edmands for use in the Time Service. Among others may be named those for making a single clock run two independent observing circuits, without the use of relays, and without interference of the observations. Spark arresters have been introduced, that on the standard clock being a sounder which gives the breaks of the clock without those of the observer. Another sounder gives the time-signals uninterrupted by the five-minute break. Experiments are in progress with a view of improving the methods of distributing standard time. One of the most important of the proposed improvements is a contrivance by which the signals may be delayed by any desired fraction of a second without affecting the clock. An error in the signals may thus be corrected without interference with the pendulum. By this means many variations in the rate of the clock may be prevented, and its performance proportionally improved.

The time-ball has been dropped correctly on 322 days at twelve o'clock by telegraph. Owing to repairs to the roof of the building, it was not dropped during an interval of thirty-five days. On five days it was dropped at twelve o'clock by hand. On two days it failed to drop at twelve, and was dropped five minutes later, according to the rule; and on one day ice on the mast prevented it from being raised.

Publication. — Volume XIII. of the Annals is now in process of publication, and will be issued as soon as it can be got through the press. It will contain the results of the work with the large telescope, under the direction of the late Professor Winlock, and also the micrometric measurements made up to the present time. Among other subjects treated will be a discussion of the focal length of the telescope and the pitch of the micrometer-screw; measurements of double stars; observations of nebulae and of their spectra; satellites of Saturn, Uranus, and Neptune; satellites of Mars during the opposition of 1877 and 1879; positions of asteroids and comets. An appendix will be added, giving an important list of errata in the zone observations of Professor Bond, kindly furnished by Dr. C. H. F. Peters. As soon as this volume is completed the printing of Volume XIV. will probably be commenced. It will contain the measures made with the meridian photometer.

The papers mentioned below have appeared during the year as communications from officers of the Observatory: —

Variable Stars of Short Period. By Edward C. Pickering, Proc. Am. Acad., xvi. 257. Reprinted in The Observatory, iv. 233, 264, 284.

Large Telescopes. By Edward C. Pickering. Proc. Am. Acad., xvi. 364. Reprinted in Nature, xxiv. 389.

Photometric Measurements of the Variable Stars β *Persei* and DM. 81° 25, made at the Harvard College Observatory. By Edward C. Pickering, Director, Arthur Searle, and O. C. Wendell, Assistants. Proc. Am. Acad., xvi. 370.

On the Probable Period of Swift's Comet. By S. C. Chandler, Jr. Astr. Nachrichten, xcix. 45.

Comet III. 1869. By Edward C. Pickering. Astr. Nachrichten, xcix. 95.

Observations of Last Contact of Solar Eclipse. By Edward C. Pickering. Astr. Nachrichten, xcix. 107.

Elements of Pechüle's Comet (*f*) 1880. By S. C. Chandler, Jr. Astr. Nachrichten, xcix. 109.

The Comparison of Sirius. By Edward C. Pickering. Astr. Nachrichten, xcix. 219.

On Certain Zodiacal Phenomena. By Arthur Searle. Astr. Nachrichten, xcix. 91, 369.

Objects remarkable for their Colors or Spectra. By Edward C. Pickering. Astr. Nachrichten, xcix. 375.

The Coefficient of Safety in Navigation. By W. A. Rogers. Proc. U. S. Naval Institute, vii. No. 2.

A review of Vol. XI. Part II. of the Annals of the Observatory, by Dr. E. Lindemann, appeared in the Vierteljahrsschrift der Astr. Gesellschaft, xvi. 108. A review of the articles on Variable Stars appeared in the Crónica Científica (Barcelona), iv. 401. Other notices of the Observatory and its work will be found in Nature, xxii. 483, 611; xxiii. 321, 338, 604; in Science, ii. 33, 107, 141, 164, 329, 447, 482; in The Observatory, iv. 81, 113, 116, 154, 245; in Copernicus, i. 139, 140.

With reference to the article on large telescopes, it may be noted that should any addition be made to the equipment of the Observatory, a telescope, mounted according to the method there described, is recommended. It is believed that in no other way could the same amount of work be obtained with a given expenditure. With our present resources, however, it is much more desirable to keep the instruments we now have actively at work than to make any addition to their number.

An important piece of bibliographical work has been undertaken, and placed in charge of Mr. Chandler. The references to observations of stars of known or suspected variability have been collected, and those of each star brought together. This portion of the work is more than half completed. The comparison stars are then to be measured photometrically, and, finally, a reduction to a uniform system to be made of all the observations of variables of long period.

Various improvements have been made in the condition of the buildings and grounds. Two wooden balconies, having an area of seven feet by seventeen, have been constructed, to replace the small iron balconies to the east and west of the large dome. They are exceedingly convenient for observations made with small instruments or with the naked eye.

In order to connect the previous determinations of longitudes by the U. S. Lake Survey with an established meridian, it was proposed by the Superintendent of the Survey to determine the difference of longitude between Detroit and Cambridge. Facilities for the work were accordingly furnished by this Observatory, and the observations required were made by officers of the Survey. Later in the season, a course of experiments on the force of gravity, by means of pendulum observations, was conducted at the Observatory by officers of the U. S. Coast Survey, who were provided with similar facilities for their work. The West Equatorial was lent for the summer months to Professor S. P. Langley, who used it in observations made on the summit of Mount Whitney, in California.

There are some advantages in an early announcement of proposed investigations, even when the preliminary experiments are not sufficiently advanced to insure their execution. The aid and advice of other astronomers may thus sometimes be secured, and the danger of duplication of work is greatly reduced. No change in the character of the work is proposed, except that an attempt will be made to restrict the work of the large telescope more closely to large pieces of routine work. Such investigations are less likely to be made at observatories where the corps of assistants is smaller, and have a value not attained by detached observations. With the ultimate object of determining the distribution of the light in the spectra of the banded stars, a stellar spectroscope has been ordered of Mr. Hilger, of London. With this it is proposed to measure the position of the principal lines in the spectra of all the banded stars as yet known. A catalogue of these objects has already been compiled. With the approval and assistance of the Selenographical Society, the photometric determination of the brightness of various points on the surface of the moon has been undertaken. The Society has furnished a list of regions suitable for standards, and the observations may be begun after the decision of some further preliminary questions. The most important of these relates to the age of the moon at which the comparisons should preferably be made. In co-operation with other astronomers, a system of standards of brightness for faint stars has been devised, and measurements of their light will be shortly undertaken.

The new meridian photometer will be used for measuring variable stars and their comparison stars, and also for determining the light of the brighter asteroids. An important piece of work is now under consideration, which would occupy this instrument for several years. During the revision of the Durchmusterung, undertaken by a number of co-operating observatories, and now approaching completion, each of the zones into which the entire region to be surveyed was divided, was somewhat extended northward and southward, so as to overlap the adjacent zones. The object of this extension was to connect the work of the different observers. Hence, the portions of the sky occupied by the overlapping borders of the zones offer a promising field for photometric research, as each determination may be compared with the estimates of magnitude made independently by two observers, with the Durchmusterung itself, with the zones of Argelander and Bessel, and with various other authorities. The number of stars to be measured is estimated at about six thousand, and the time required for the observations with the new meridian photometer would be at least three years.

EDWARD C. PICKERING, *Director*.

THIRTY-SEVENTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE, NOVEMBER 22, 1882,
AND LAID BEFORE THE BOARD OF OVERSEERS,
JANUARY 10, 1883.

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1883.

REPORT

OF THE

DIRECTOR OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE

FOR 1881–82.

TO THE PRESIDENT OF THE UNIVERSITY:

SIR, — The progress made in the reduction of the past observations has been the distinguishing feature of the last year. The micrometric observations of the large telescope, to the beginning of 1882, have been published, and the volume has been distributed. A large part of it is occupied with the work of my predecessor, the late Professor Winlock, upon double stars, nebulæ, and other objects, including spectroscopic results. The reductions of the zone observations made with the meridian circle from 1871 to 1879 are now approaching completion. The meteorological observations from 1840 to 1880 have been brought together and are nearly ready for publication. The most important piece of photometric work as yet undertaken here has been completed, and the catalogue giving the results of the measures of four thousand stars is now in the hands of the printer. It thus appears that if the present rate of work is maintained, it will not be long before the accumulated observations of the past are reduced and printed, and we may anticipate a publication of our future observations without a delay greater than is needed for their reduction.

The work of the various instruments will now be considered in detail.

EAST EQUATORIAL.

Eclipses of Jupiter's Satellites. — The observations of these eclipses photometrically, begun in 1878, have been continued during the past year. One hundred and eighty-five eclipses have been observed, thirty-two since Nov. 1, 1881.

Objects having singular Spectra. — The search for these objects in previous years has been mainly in regions selected without special system. The heavens have now been divided into sections of equal area, and a rectangle of 5° by 10° in the centre of each has been selected for examination. The twelve regions having centres at declination + 15° and right ascension 1^h, 3^h, 5^h, etc., have all been swept over in this way. Of the twelve corresponding regions having a declination of — 15° six have so far been examined. From this systematic search, we may learn in what portion of the heavens we may expect to find objects of interest, and thus justify a more extended examination. The absence of such objects in other regions will also show that a further search in their vicinity is unadvisable. Several minute planetary nebulæ have been found near the Milky Way, but none at a distance from it. A special search was therefore made last summer in the Milky Way from — 30° to + 20°. This resulted in the discovery of seven new planetary nebulæ. Most of these objects, although moderately bright, are so minute that they could not be distinguished from stars by an ordinary eyepiece. One of them has hitherto been mistaken for a star, and is given in the catalogues as DM. + 1° 3979.

Satellites of Mars. — At the last opposition of Mars the satellites were looked for and were repeatedly seen by Mr. Wendell and myself between December 16 and February 24. It thus seems probable that these objects may be seen with our telescope at any opposition of the planet. The observations made of them here on this occasion were entirely photometric. The results were in general confirmatory of those obtained at the oppositions of 1877 and 1879, but the difference between the brightness of Deimos when preceding and when following Mars, which had been formerly noticed, was not now apparent.

Lunar Objects.—The photometric determination, for the Selenographical Society, of the brightness of various points on the Moon, mentioned in the last report, was completed and the results communicated to the Society. They appear in the Selenographical Journal, V. 57. It appeared from this investigation that the scale of brightness in common use by observers of the Moon might be very closely expressed in terms of stellar magnitudes, each degree of the scale answering to the ratio of light equivalent to six tenths of a magnitude.

Double Stars. — As a part of the bibliography noted below, a list has been prepared of the double stars, the variability of whose components has been suspected. The photometer employed in the observations discussed in Volume XI. Part I., is especially suited to observing such objects. The usual methods of detecting variability fail when applied to the double stars. One of the most striking instances in this list is the star *θ Serpentis*, one component of which has been thought to be variable by Dr. Gould. According to our observations on three evenings in 1878, the respective differences in magnitude of its components were 0.5, 0.5, and 1.4. It has been repeatedly measured during the past year with the results 0.4, 0.4, 0.4, 0.5, 0.4, on different evenings. In general each of these numbers is the mean of sixteen settings. If really variable, the star probably belongs to the Algol class, and this conclusion seems unavoidable unless the wrong star was observed in the last measures in 1878. The measures show the great precision attainable with this form of photometer.

Wedge Photometer. — A modification has been made of Professor Pritchard's wedge photometer which seems to render it especially suitable to the measure of the light of faint stars in zones. The wedge is placed so that the diurnal motion of the stars carries them from its thin to its thick portion, and the time of disappearance is noted. A bar in the unobstructed part of the field serves to determine the position of each star. From 1852 to 1860 the measurement of the positions of the stars from the equator to one degree north formed an important part of the work of the large telescope. The stars in the northern 10′ of this zone have been arranged in catalogue form, and the necessary preliminary observations have been made by Mr. Searle. Besides determining the light of these objects it is hoped that some interesting cases of proper motion may be detected.

Sawyer's Variable. — A careful study of this interesting star by Mr. Chandler proved that it belonged to the Algol class, and also that its period was only about twenty hours. This gives it the shortest period of any variable star as yet discovered, and only a little more than one third of the period of any other variable of the same class. The variation of light is about three fourths of a magnitude. A long series of observations of the light curve and of successive minima has been made by Mr. Chandler, and gives the period $20^h\ 7^m\ 41^s.6$, with a probable error of $1^s.3$.

The comparison stars were measured on ten nights with the meridian photometer, and furnished a means of reducing these observations to absolute light ratios. The light curve has also been determined photometrically by Mr. Wendell and myself. Observations were made on eighteen nights and give a very precise measure of the changes of light.

Comets. — The telegraphic system for the speedy transmission of various data respecting comets, which was mentioned in the last report, has been maintained and extended. The first observation of a new comet which is obtained at this Observatory is now telegraphed to Europe in advance of the elements, and is often found useful by European computers. It has happened in two cases, those of the comets discovered by Messrs. Wells and Barnard, that the receipt of the position obtained here was the first intimation abroad of the discovery. This led in the case of the Wells comet to the supposition that the discovery had been made at this Observatory, and to guard against similar errors in future, the despatches are now made fuller, giving the facts of discovery as well as the positions. Arrangements have also been made with Mr. Swift, director of the Warner Observatory at Rochester, in accordance with which he forwards information received by him of new discoveries, either for immediate transmission to Europe, or for a previous investigation here.

The four comets, discovered respectively by Swift in 1881, by Wells and Barnard in 1882, and by various southern observers (the great comet of the year), will show the working of this system. In each case, an observation was obtained at this Observatory on the night following the receipt of intelligence of the discovery, and an orbit was computed, telegraphed to Europe, and published by the Science Observer in this country, during the next four days. In two cases, the accurate position obtained here, and telegraphed in advance of the orbit, was published abroad on the day following that on which the news of the discovery reached us. The orbit of Swift's comet sent from this Observatory first announced its discovery to European astronomers, as likewise happened in two cases already mentioned with regard to the first observation obtained here. These first observations were extensively used in the computations made in Europe. Cloudy weather prevented sufficient data for an orbit of the great comet from being secured here in the first few days of its appearance; but, on receipt by telegraph from Europe of one more position, the orbit was computed and telegraphed back within seven hours.

MERIDIAN CIRCLE.

After continuous observations extending over twelve years, Professor Rogers has found it necessary to take a prolonged rest from night work. The interrupted series will be resumed in February, 1883. Meanwhile the instrument has been used in determining the local time. Its constants, including the collimation, the level, the flexure, the reading of the long collimator, and the index error of the circle, have been determined every week. Excellent progress has been made with the reduction of the observations from 1870 to 1879. These observations will occupy about twelve hundred printed pages, and will fill three volumes of the Annals. The subject will probably be divided according to the following plan. The first volume will contain an introduction giving a description of the processes of observation and of reduction, and a discussion in detail of the instrumental constants for the entire period. The tabular values of these constants will be given for each date. The greater portion of this volume will be devoted to a table which will give the mean times of transit, the circle readings, the constants needed in the reduction, and the resulting right ascension and declination of each of the fundamental stars observed. The second volume will contain all the zone observations in journal form. The quantities used in the reduction of the zone stars will also be given in this volume. The third volume will contain the observations of the secondary polar stars observed during the years 1872–73, the observations of a list of stars made at the request of the United States Coast Survey in 1878, and all the miscellaneous observations made previous to 1879. The second part of this volume will contain the final catalogues of the primary stars, of the secondary stars, and of the zone stars reduced to 1875.0

The introduction to the first of these volumes, occupying one hundred and fifty pages of manuscript, is completed and is ready for publication. The data for the body of the work are also complete except the introduction of the newly determined instrumental constants depending directly upon the system given in Publication XIV. of the Astronomische Gesellschaft. The preparation of the copy for publication has recently been commenced.

Of the second volume, the reduction of the zone observations to the beginning of the year of observation has been completed, and the copy containing the original data has been prepared for the printer. It occupies about six hundred pages of manuscript. The reduction of the Durchmusterung places from 1855 to 1875 is nearly completed. A large part of the reductions of the zone observations are to be examined either by cross checks or by recomputation. All doubtful observations are to be investigated, and the positions are to be reduced from the beginning of the year of observation to 1875.0 by means of manuscript tables.

The only portion of the third volume which is ready for publication is that containing the observations of the Coast Survey Catalogue. This occupies one hundred pages of manuscript. The reduction of the Polar Catalogue with the newly determined instrumental constants, and the formation of the final catalogues, still remains to be made.

MERIDIAN PHOTOMETER.

The measurement of the light of the stars visible to the unaided eye was completed last summer. Over ninety thousand measures were made on about four thousand stars, most of them being observed on from three to six nights. The more important stars were measured more frequently. Four settings were made every evening on each object. A series of estimates by the unaided eye have also been made by three observers for purposes of comparison. The entire work will involve the discussion of several problems of general interest in connection with the light of the stars. Among these may be mentioned the atmospheric absorption. A discussion of about fifteen thousand observations available for this investigation shows that we may assume that the absorption at any altitude, exceeding 15°, equals in stellar magnitudes one quarter of the secant of the zenith distance. This agrees very nearly with the empirical law deduced by Seidel, especially if we apply a correction for the low barometric pressure due to his great elevation. The average deviation of the two laws does not exceed a thirtieth of a magnitude. A special series of eye estimates serves to extend this law to the horizon.

The constancy of the Pole Star is established by the same observations with the photometer. A series of eye estimates was also made to compare the light of the Pole Star with that of other stars of nearly equal brightness near it, and shows that the relative position of two stars to be compared has an important influence in their apparent brightness. After applying a proper correction, the average deviation of the results is reduced to six one hundredths of a magnitude. An extended comparison of the scale of magnitudes employed by previous observers has been made. A reduction of the observations of Sir William Herschel has been effected, and has led to interesting results. His observations of the light of the stars are not only far superior to any similar work preceding it, but are more precise than most of the subsequent determinations. Their neglect hitherto is partly due to the want of a suitable system of magnitudes by which they might be reduced. This want is supplied by the photometric measures now under consideration. There seems also to have been an impression that the intervals employed by Herschel were so large as to render the observations uncertain. Our reduction shows that the intervals he designated as a period, comma, and dash, do not exceed one, two, and four tenths of a magnitude; and that the average deviation of a single comparison of two stars, expressed in magnitudes, is only 0.25. As this includes the error of our measurements of each star, the difference of each as seen by the eye from its true brightness, and the variation each has undergone during the past century, it is obvious that the errors of Herschel's observations must be very small. We have thus an accurate measure of the brightness of a large part of the lucid stars a hundred years ago. This will be of the utmost value in determining any changes of long period that may take place in their light.

The large meridian photometer announced in my last report has been completed, and work with it begun. Sheets have been written for about ten thousand stars to be observed with this instrument. Over seven thousand measures have so far been made, mainly of the stars in the over-lapping portions of the zones assigned to different observatories engaged in the revision of the Durchmusterung. The measurement of the stars adopted as standards for the Uranometria Argentina is also in progress.

PUBLICATIONS.

Volume XIII. Part I., of the Observatory Annals, was published and distributed in October, 1882. It contains the previously unpublished results of micrometric observations made here to the end of 1881, mentioned in detail in the report of last year.

The printing of Volume XIV. is now in progress. This volume is to contain the results obtained with the first meridian photometer. The part of the work first printed consists of a catalogue of stars visible to the naked eye in this latitude, with their magnitudes as determined by the photometer, by the recent estimates of the northern stars likewise made here, and by various older series of observations.

The papers mentioned below have appeared during the year as communications from the officers of the Observatory. A few are added to the list which were overlooked in the preparation of the last report.

Report of the Committee on Standards of Stellar Magnitude. By Edward C. Pickering and others. Proc. Am. Assoc. for Advancement of Science, August, 1881; xxx. 1.

On a Convenient Method of expressing micrometrically the Relation between English and Metric Units of Length on the same Scale. By W. A. Rogers and G. F. Ballou. Id. xxx. 116.

On a Method of reducing Different Catalogues of Stars to a Homogeneous System. By W. A. Rogers. Id. xxxi. 11.

On the Performance of a New Form of Level invented by Mr. John Clark of the United States Coast Survey. By W. A. Rogers. Id. xxxi. 14.

New Variable Star in Puppis. By Edward C. Pickering. Astronomische Nachrichten, c. 13.

Elements of Comet *b* 1881. By S. C. Chandler, Jr. Id. c. 121.

Elements and Ephemeris of Comet *e* 1881. By S. C. Chandler, Jr. Id. c. 319.

On the Telegraphic Transmission of Astronomical Data. By S. C. Chandler, Jr., and J. Ritchie, Jr. Science Observer, August, 1881, iii. 65.

Comet *b* 1881. By O. C. Wendell. Id. iii. 81.

Report on the Progress of the Zone Observations. By Edward C. Pickering. Vierteljahrsschrift der Astronomischen Gesellschaft, 1881, xvi. 317.

Letter to the Astronomische Gesellschaft on the Science Observer Code. By S. C. Chandler, Jr., and J. Ritchie, Jr. Id. xvi. 344.

Order of Brightness of Stars. By Edward C. Pickering. English Mechanic and World of Science, November, 1881, xxxiv. 278.

Remarkable Star Spectrum; New Planetary Nebula. By Edward C. Pickering. Science, December, 1881, ii. 581. Copernicus, December, 1881, i. 242.

Geodetic Formulæ. [Second Paper.] By J. Rayner Edmands. Appalachia, December, 1881, ii. 351.

Elliptic Elements of Comet *f* 1881 — Denning. By S. C. Chandler, Jr. Science Observer, December, 1881; iii. 91.

Reply to Inquiries regarding Time Balls. By Edward C. Pickering. Professional Papers of the Signal Service, No. 5, p. 24.

Observations and Elements of Barnard's Comet, 1881, VI. By S. C. Chandler, Jr. Astronomische Nachrichten, ci. 57.

Stars with Peculiar Spectra, discovered at the Astronomical Observatory of Harvard College. By Edward C. Pickering. Id. ci. 73.

On the Periodicity of Comet (Denning) 1881, V. By S. C. Chandler, Jr. Id. ci. 93.

Observations of Comets, 1881, V., and 1881, VIII. By O. C. Wendell. Id. ci. 231.

Observations of Comets, 1880, IV., and 1881, II. By O. C. Wendell. Id. ci. 299.

The Pleiades. By Edward C. Pickering. Astronomical Register, February, 1882, xx. 40.

Variable Stars. By Edward C. Pickering. English Mechanic and World of Science, February, 1882, xxxiv. 542.

On the Variability of DM. + 23° 1599. By S. C. Chandler, Jr. Astronomische Nachrichten, cii. 139.

Photometric Observations of Planets and of Jupiter's Satellite, III., made at the Harvard College Observatory. By Edward C. Pickering. Id. cii. 151.

Photometric Observations of the Satellites of Mars, 1881–82. [E. C. Pickering and O. C. Wendell, observers.] By Edward C. Pickering. Id. cii. 193.

Erratum in Observations of Comet Wells, 1882. By Edward C. Pickering. Id. cii. 223.

On Certain Zodiacal Phenomena. By Arthur Searle. Id. cii. 263.

On Sawyer's Variable, DM. + 1° 3408. By S. C. Chandler, Jr. Id. cii. 371.

On a New Variable Star in the Constellation Cetus. By S. C. Chandler, Jr. Science Observer, March, 1882; iii. 105.

The Mountains between Saco and Swift Rivers. [With map.] By J. Rayner Edmands. Appalachia, June, 1882; iii. 57.

The Meridian Photometer. By Edward C. Pickering. Monthly Notices of the R. Astr. Society, June, 1882, xlii. 365.

Photometric Comparisons of Lunar Objects. By Edward C. Pickering. Selenographical Journal, July–August, 1882; v. 53, 57.

On Certain Zodiacal Phenomena. By Arthur Searle. Science Observer, July, 1882, iv. 4.

On Sawyer's Variable, DM. + 1° 3408. By S. C. Chandler, Jr. Id. iv. 11.

Photometric Measurements of Sawyer's Variable (DM. + 1° 3408) and its Comparison Stars. By Edward C. Pickering. Astronomische Nachrichten, ciii. 61.

New Planetary Nebulæ. By Edward C. Pickering. Id. ciii. 95, 165.

Observations of Comets, 1881, III., IV., VI. By O. C. Wendell. Id. ciii. 145.

Small Planetary Nebulæ, discovered at the Harvard College Observatory. By Edward C. Pickering. The Observatory, October, 1882, v. 294. The Sidereal Messenger, October, 1882; i. 139.

Plane *v.* Cylindrical Surfaces. By W. A. Rogers. Mechanics, No. 31, p. 90.

A Study of the Problem of Fine Rulings with respect to the Limits of Naked Eye Visibility and Microscopic Resolution. By W. A. Rogers. Am. Monthly Microscopical Journal, September, 1882, p. 165.

A Comparison of the Harvard College Observatory Catalogue of Stars for 1875.0 with the Fundamental Systems of Auwers, Safford, Boss, and Newcomb. By W. A. Rogers. Memoirs of the Am. Acad. of Arts and Sciences, x. 389–429.

On the Conditions of Success in the Construction of Standards of Length and in their Subdivision into Equal Parts. Read before the American Society of Microscopists at the meeting held at Elmira, N. Y., August, 1882. By W. A. Rogers. Mechanics, Oct. 27, 1882, and later.

A Plan for Securing Observations of the Variable Stars. By Edward C. Pickering. Cambridge, 1882. 8°.

On the Period of R Hydræ. By S. C. Chandler, Jr. Astronomische Nachrichten, ciii. 225.

Variable Stars. — The bibliography of the variable stars undertaken by Mr. Chandler last year has been nearly completed, so far as the preparation of the list of references is concerned. The catalogue of stars suspected of variability, and the remarks relating to each, are nearly complete. A plan has been prepared for securing co-operation in the observation of these objects. A pamphlet has been published relating to this matter, and will be furnished to all persons making application for it. It is hoped that many astronomers will be inclined to aid in this work, as observations which if detached might have little value would be most useful as part of an extensive system of observations. The aid of amateurs is especially invited, since the necessary skill is soon acquired and the habit of making observations of permanent utility would often have a value as great as the direct results anticipated. The aid of lady observers is also desired, since much useful work could be done by them at their own homes. Among the many ladies owning telescopes are doubtless some who have the time and inclination, and might, if properly directed, make observations of great value to science. The observations of the light curves of the variable stars of long period have been much neglected, and observations with this object in view are also needed. A number of observers have promised their aid, and by next year I shall hope to report a large amount of useful work accomplished.

MISCELLANEOUS.

Cambridge was not selected by the United States Commission as a station for observing the transit of Venus. This was in some respects unfortunate, as a complete series of observations were made here in 1878 of the transit of Mercury. This was done at the request of the Naval Observatory, with the expectation that we should thus be prepared to observe the transit of Venus at the present time. On the other hand it is extremely doubtful whether the results obtained during the transit will add materially to our knowledge of the distance of the Sun, and the chance of a cloudy day is twice as great as that of a clear one. I regard the expenditure of money on large pieces of routine work, where a result of value is certain to be secured, as more advisable than any large expenditure for observing occasional phenomena, where clouds may prevent the attainment of any result. If clear, the contacts will be observed, with such other facts as can be noted without much previous expenditure of time or money. Photographs might have been taken without the aid of the United States Commission; but, as they would necessarily have been made according to a somewhat different system, it is doubtful whether they would have added to the value of the whole.

During the past year, no change has occurred in the corps of assistants, which remains as described in the last Report. The buildings and grounds have been kept in good order without alteration, except that an additional flight of steps has been placed near the southwestern corner of the building, to make the path along its southern side more readily accessible. The West Equatorial has been removed from its pier for use in experiments on the horizontal mode of mounting telescopes, and its place is temporarily supplied by an excellent six-inch refractor belonging to Mr. Chandler.

The time service, in general charge of Mr. Edmands, has been carried on successfully as in previous years. The time ball was dropped correctly on three hundred and fifty-nine days, three hundred and seventeen by telegraph and forty-two days by hand. On three days it failed to drop at twelve o'clock, and according to the rule was dropped precisely five minutes later. On two days it was impossible to obtain the signals, and on one day an accident to the machinery rendered it impossible to raise the ball.

FINANCIAL CONDITION.

Having thus considered the scientific work of the Observatory, its present critical financial condition may be stated briefly. The subscription of 1878, which has given us an increase in income of five thousand dollars, expires with the present year. With this, three instruments instead of one have been kept at work, the corps of assistants has been doubled, excellent progress has been made in reducing the observations of the past, and a large number of volumes of annals and brief publications have been issued. An attempt is now being made to secure a fund of one hundred thousand dollars to render permanent this increased rate of work. Over thirty thousand dollars have already been promised conditionally, the principal limitation being that at least seventy-five thousand dollars shall be secured before next September. A failure in this subscription will involve a return to the condition of comparative inactivity which we were previously obliged to maintain. With success, we shall have the means of accomplishing the amount of work to be expected from the standing of this University, and demanded by the advanced views regarding literary and scientific work held in this part of the country.

EDWARD C. PICKERING, *Director*.

THIRTY-EIGHTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE, DECEMBER 19, 1883, AND
LAID BEFORE THE BOARD OF OVERSEERS, JANUARY 9, 1884.

BIBLIOTHECA BODLEIANA

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CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
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ANNUAL REPORT

OF THE

DIRECTOR OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.

1882-83.

To the President of the University:

Sir, — During the past year the subscription of five thousand dollars annually for five years, which was secured in 1878, has expired. To replace it an attempt has been made to raise by subscription the sum of one hundred thousand dollars as a permanent fund. Up to the present time about fifty thousand dollars have been promised for this purpose, the income of which will permit a large amount of useful work to be carried on permanently by the Observatory. This sum will be sufficient to prevent the sudden restriction of scientific operations, which would otherwise have been inevitable on the expiration of the subscription of 1878. It is hoped that additional donations may eventually increase this fund to one hundred thousand dollars, and thus permit the same degree of activity to be maintained as during the past five years.

I give my best thanks to the ladies and gentlemen who by their generous gifts have aided the Observatory at this critical period in its history. Their names, with the amount of the subscription of each, are given below in alphabetical order. Asterisks indicate subscribers to the temporary fund of 1878, as well as to the present permanent fund.

List of Subscribers.

NAME.	AMOUNT.	NAME.	AMOUNT.
A Friend	$10,000	* H. H. Hunnewell	$1,000
* W. Amory	2,000	S. Johnson	250
Francis Blake	500	* H. P. Kidder	2,485
* J. I. Bowditch	5,000	A. A. Lawrence	500
* Martin Brimmer	500	A. T. Lyman	500
Shepherd Brooks	500	* T. Lyman	200
T. Q. Browne	500	* W. P. Mason	200
* J. A. Burnham	1,000	* F. H. Peabody	500
* C. F. Choate	500	* O. W. Peabody	250
Wm. Claflin	200	* E. C. Pickering	1,000
Alex. Cochrane	200	H. B. Rogers	1,000
* C. P. Curtis	1,000	* Stephen Salisbury	2,000
J. C. Delano	250	* Mrs. D. Sears	200
W. Endicott, Jr.	2,000	* N. Thayer	5,000
* J. M. Forbes	1,000	* C. E. Ware	500
* Geo. Gardner	100	* Miss Wigglesworth	200
* J. L. Gardner	500	* R. C. Winthrop	250
R. C. Greenleaf	500	R. C. Winthrop, Jr.	100
* Mrs. A. Hemenway	2,000	Mr. and Mrs. J. H. Wolcott	200
* G. Higginson	5,000		

I take this occasion to gratefully acknowledge the aid of the Visiting Committee, to whose efforts both this fund and the subscription of 1878 are due. It is hoped that the results attained will satisfy the friends of the Observatory that this increase in income has been a judicious application of money to scientific purposes. The increase in the number of assistants and of instruments in active use is especially to be noted.

In the present distribution of observatory work, my own observations are chiefly made with the large equatorial and the meridian photometer. Mr. Wendell takes part in the observations with both these instruments, and Professor Searle in those made with the equatorial. Messrs. Cutler and Eaton assist in recording these observations. Their reduction is carried on by Miss Farrar, Mrs. Fleming, and Mr. Cutler, with the aid and partly under the supervision of Mr. Wendell. Their preparation for the press and publication are conducted by Professor Searle and myself. The meridian circle remains in charge of Professor Rogers, who is aided in the observations by Mr. Pratt, and in their reduction also by Mrs. Rogers, Miss Saunders, Miss Bond, Miss Winlock, and Mr. Eaton. The equatorial mounted in the small dome is actively employed by Mr. Chandler, mainly in the observation of variable stars. He is assisted in the reductions by Mr. Metcalf. The time signals are in charge of Mr. Edmands. The meteorological observations and the ordinary business matters of the Observatory are usually conducted by Professor Searle. The computation of cometary orbits is undertaken by Mr. Chandler, and the announcements of astronomical discoveries and results by telegraph or by published circulars are in charge of Mr. Ritchie.

EAST EQUATORIAL.

Eclipses of Jupiter's Satellites. — Photometric observations of these eclipses have been continued upon the system adopted in 1878. In all, two hundred and forty eclipses have now been observed, fifty-five since the end of October, 1882. Some observations were also made last spring to determine the accuracy with which occultations and transits of Jupiter's satellites could be observed. The method heretofore in use has been to observe the times of contact, but these are not easily determined, from the indefinite outlines of the planet and its satellites. The observations just mentioned were made with a double image micrometer. An image of the satellite was placed midway between the two images of Jupiter, and the time of the setting was recorded. Each measure of this kind furnished a determination of the distance between the centres of the planet and satellite, and a large number of measures could be obtained on each occasion instead of a single estimate of contact. The result showed that the time of an occultation or transit could thus be determined with a probable error of about nine seconds, which is less than the probable error in observing an eclipse by the old method.

Revision of Zone Observations. — The stars between 50′ and 60′ north of the equator for the epoch 1860, and occurring either in the zones published in Volume VI. of the annals of this Observatory or in the Durchmusterung, have been twice observed by Professor Searle with the modified wedge photometer described in the last Report. The transit of each star over a bar, and its subsequent disappearance in the wedge were recorded by the chronograph, while its approximate declination was estimated with the aid of three transverse bars 5′ apart. The reduction of these observations is far advanced, and the examination of discrepancies between them and those made under Professor Bond's direction has been begun, for the purpose of detecting any cases of considerable proper motion or variability which may exist in this zone of 10′ in width. Differences amounting in right ascension to $0^s.5$, and in declination to $0'.5$, are investigated by more accurate observations when the discrepancy is not explained by an error in reduction. A difference of three quarters of a magnitude in the two separate results obtained with the wedge photometer is also regarded as large enough for special examination. The number of stars which require re-observation does not thus far seem likely to be great. Even a merely negative result with respect to proper motion will have some interest, as it will tend to establish the comparative fixity of the fainter stars, which is at present assumed rather than known. As Professor Bond's zone observations were finished in 1860, the interval between them and the present revision is sufficient to bring into notice any case of annual proper motion much in excess of 1″, either in right ascension or in declination. In the provisional reduction of the photometric portion of the work, the scale of magnitude is made to depend upon the Durchmusterung, but it is expected that the meridian photometer will soon provide the means for a more complete reduction.

Objects having singular Spectra. — The search for these objects has been continued; the regions selected for examination have been chiefly in the Milky Way, but little time has been devoted to this work on account of the use of the large telescope for more important purposes.

Standards of Stellar Magnitude. — In accordance with a plan proposed in the Proceedings of the American Association for the Advancement of Science, xxx. 1, it is intended to form charts of the stars in small areas 4^m in extent in right ascension and 10′ in declination. The centre of each area follows one of a selected series of twenty-four bright equatorial stars at an interval of 4^m, in the same declination. Besides making the charts, it is proposed to determine the magnitudes of a sufficient number of faint stars in each region to exhibit a scale of magnitude to which reference may readily be made by observers who desire their estimates to be directly comparable with those of others.

In obtaining material for the proposed charts, various plans have been tried, with the view of economizing time so far as practicable. Data have been collected for several stars, sufficiently complete to enable the construction of the charts to be undertaken.

Comets. — The present arrangements for the distribution of astronomical intelligence, to be further mentioned below, insure the early receipt at this Observatory of the news of cometary discoveries, so that the first accurate observations of a comet may often be made here. This was the fact with regard to each of the two comets found during the year. The observer was Mr. Wendell. The positions he obtained were extensively employed in the computation of orbits by various astronomers, and preceded by twenty-four hours those obtained elsewhere.

Variable Stars. — The large telescope has been frequently used in observing variable stars, too faint to be visible with the west equatorial, the work of which is mentioned below. The collection of data for charts of the immediate neighborhood of many variable stars has also been undertaken with the large telescope.

Spectra and Color of Stars. — This subject has long been under consideration, in the hope that good means may soon be found of determining the position of the lines and the distribution of the light in different types of stellar spectra. As yet, the observations made have been experimental and preliminary. A large spectroscope was ordered from Hilger, of London, for the purpose of research in this direction, and was received early in 1882. Owing, however, to the difficulty which the maker of the instrument found in understanding, from mere correspondence, the essential objects to be aimed at in its construction, this spectroscope has not proved satisfactory for the proposed work. A more promising form of apparatus is now under consideration.

MERIDIAN CIRCLE.

After an interruption of about a year, the fundamental observations with the meridian circle were resumed on February 8, 1883. Before the commencement of the work the level and azimuth of the instrument were brought nearly to zero, by scraping the segmental bearings of the pivots. Between February 8 and November 1, 2383 observations were made of the fundamental stars, 136 of Polaris, and 121 of the Sun, making in all 2640. As heretofore, all the instrumental constants are referred to Polaris alone. An average of 10.5 independent determinations of the declination of this star have been made at each transit. The actual number of declinations observed is 1420.

The level of the instrument as determined with the Clark reversible level has remained remarkably constant during the year, the entire range of variation having been only $0^s.17$. The individual measures differ on the average by about $0^s.02$ from the adopted mean values.

As formerly, the reversible level has been used to determine the variation of the index error of the circle for the interval during successive transits of the Pole Star. The long collimator has been used for the same purpose during observations near the equinoxes and the solstitial points; but on account of the variation of the fixed point of the collimator during the daytime, and especially on account of the frequent unsteadiness of the image, the results obtained are far less satisfactory than those derived from the level.

A series of observations undertaken for the determination of the longitude of McGill College Observatory, Montreal, extended from June 2 to June 23 inclusive. The plan of the campaign involved an exchange of observers in addition to the determination of personal equation by the usual methods. Accordingly, after three nights at Cambridge and Montreal, Professor Rogers exchanged stations with Professor McLeod. The results for personal equation at each station are as follows: —

MONTREAL.	CAMBRIDGE.
Rogers, *minus* McLeod.	Rogers, *minus* McLeod.
June 13 + $.096^s$.	June 28 + $.143^s$.
June 14 + .111.	June 30 + .144.

The observations at Cambridge were made with the Russian Transit, but simultaneous observations were made with the meridian circle by Mr. Brown. The whole number of observations made during the series is about 400, and their reduction is nearly completed.

After the completion of the reduction to 1875.0 of the zone observations made between 1870 and 1879, it was found by direct comparison with the Durchmusterung positions brought forward to the same epoch, that observations were wanting for 306 stars. It was also found that in many cases, especially between 19 hours and 1 hour of right ascension, the wrong star was observed when there were two or more stars in the same field. During the observations no less than 528 stars were for various causes marked in the observing records as not seen. Since, in a large number of cases, the failure to observe was due to the faintness of the stars under a bright field illumination, it was thought desirable to improve the character of the illumination before commencing the work of re-observation. Accordingly, Mr. George B. Clark, after a series of experiments with a dark field illumination for lines ruled upon glass, arranged a set of mirrors in the tail-piece of the telescope, by which the light, passing from a lamp swinging upon gimbals, through an opening in the tube, is thrown down upon the glass plate in two planes at an angle of about 45°.

When a red-shade glass is interposed, an even illumination is obtained, under which stars of the tenth or eleventh magnitude can be easily seen.

The re-observation of the scattering zone stars was begun October 9, and between this date and November 1, 512 observations were made. The gap which has been filled extends from 19^h 40^m, to 1^h.

The reduction to 1875.0 of the zone observations made between 1870 and 1879 has been completed. The reduction of the observations of fundamental stars for the same interval is also completed. The entire computing force assigned to the Meridian Circle is now engaged in the preparation of copy for publication. This work will be completed in about five weeks.

It will be seen therefore that practically two volumes are ready for publication. The third volume, containing the observations of secondary stars brighter than the magnitude 6.5 and the final catalogues, is in a forward state of preparation.

The final catalogues will depend upon about 46,600 observations, distributed as follows: observations of zone stars, 24,300; of primary stars, 15,200; of secondary stars brighter than the magnitude 6.5, 7,100.

MERIDIAN PHOTOMETER.

The position of this instrument, as a permanent portion of the Observatory work, may now be regarded as fairly established. After a thorough trial it has shown itself capable of determining absolute stellar magnitudes more satisfactorily than any other photometer that we have tried. It bears the same relation to photometry that a transit circle does to measurements of position, and will be regarded as the standard to which all our other measures will be reduced. As it is capable of measuring any star of the ninth magnitude or brighter, its field of work is, for the present, indefinitely great. We are now able to determine satisfactorily the brightness of any such stars when they are desired for any special purpose by other astronomers.

One hundred and thirty-three series, including about twenty thousand sittings, have been made since November 1, 1882, by Mr. Wendell and myself. The most important investigation in progress has been the revision of the Durchmusterung magnitudes. The results of the estimates of brightness made at thirteen observatories, and extending over a period of ten or fifteen years, will thus be brought together and reduced to a single system.

The stars adopted as standards in the Uranometria Argentina, have been observed with this instrument on at least three nights each. The scale has thus been determined in terms of the photometric scale. A comparison has also been made with the measures of the brighter of these stars, obtained with the small meridian photometer. The results with the new instrument are on the average 0.04 magnitudes fainter. This difference is so small that its existence may be regarded as doubtful. No systematic difference depending upon the right ascension is perceptible. On the other hand, a comparison with the Durchmusterung, Uranometria Argentina, and a series of eye estimates, indicate well-marked systematic errors in these catalogues, due to the presence of the Milky Way. In seven and eighteen hours of right ascension the stars are estimated two or three tenths of a magnitude too faint in each of these catalogues. The proximity of bright stars, especially those in Orion, appears a reasonable explanation of this source of error.

Some miscellaneous observations have also been taken, of which the most interesting are those of Neptune, of the comparison stars of *S Cancri*, and of other variables. Observations of Neptune on eleven nights give its light as 7.71 ± .02.

MISCELLANEOUS.

Variable Stars. — The study of the variable stars by Mr. Chandler has been an important part of the Observatory work. The bibliography is nearly completed so far as the first extraction of references is concerned. Notes have been prepared to exhibit the evidence of variability which has been published with regard to about twelve hundred stars. This list excludes many cases in which the evidence is entirely inadequate. A table, giving all the published maxima and minima of each of the variables of long period, is now in process of construction. The preparation of this table has led to the important result that an interval of several years occurs in which no observations appear to have been made of about thirty of these objects. About one hundred and forty stars belong to this class, and since last April all of them have been observed by Mr. Chandler, with the six-inch Clacey Equatorial mounted in the west dome. According to the present plan of work, he observes each of these stars at least twice a month, and more frequently during its brightest phases. Charts of the vicinity of these variables have been prepared, and some progress made towards their completion. Similar charts have been made for about seventy telescopic stars suspected of variability, and nearly two hundred observations of these stars have been obtained. The color of the variable stars is also estimated, about three hundred observations of this class having already been made.

A circular was distributed asking the aid of amateurs and others in the observation of stars known or suspected to be variable. It is believed that by co-operation much valuable material may be collected and much time saved. Numerous replies have been received and important results have been obtained, especially by Mr. H. M. Parkhurst, of New York, and by the Rev. J. Hagen, S. J., of Prairie du Chien, Wisconsin. The great difficulty encountered by most of the observers was that of identifying with certainty the fainter stars, although this is one of the first things that should be learned by any person desiring to do useful astronomical work.

Astronomical Photography. — With the assistance of Mr. W. H. Pickering, Instructor in Physics at the Massachusetts Institute of Technology, an investigation was undertaken in astronomical photography. Two objects were kept in view: first, the determination of the light and color of the brighter stars, and, secondly, the construction of a photographic map of the whole heavens. After numerous preliminary observations, a method was employed by which a photograph of the brighter stars included in about one-twelfth of the entire heavens could be obtained on a single plate.

Maps were also obtained containing a region of about 15° square, containing stars as faint as the eighth magnitude. The color exercised a marked influence on the intensity of the photographic images, in some cases producing a difference equivalent to four magnitudes. It is thought that photography may offer the most delicate test we yet have of the color of a star, — differences too small to be perceptible by the eye becoming distinctly visible in the photographic images.

A circular has been issued to request the donation of specimens of astronomical photography, to be added to those already belonging to this Observatory. Many of the early efforts to render this mode of research available were made by Professors W. C. and G. P. Bond, and the numerous results of their work now preserved here have great historical interest. The photographs of the solar eclipses of 1869 and 1870, taken under the direction of Professor Winlock, form another important portion of the collection. It is hoped that the additional specimens received in response to the circular will permit the formation here of a series fully illustrating the origin and progress of astronomical photography. Many fine examples of the art have already been presented to the Observatory. It is intended hereafter to issue a catalogue of the collection, in which the proper acknowledgment will be made of the liberality of each contributor to it. It will be desirable at the same time to indicate the existence of other important astronomical photographs, and the places where they are preserved. Information of this description will accordingly be gratefully received. Original negatives, or prints on glass from such originals are especially welcome, since they are free from many of the defects of paper prints. Much inconvenience and delay in the reception of these specimens, and of any gifts intended for the Observatory which cannot be sent by mail, may be avoided by forwarding them by a vessel bound for Boston, instead of by one destined for New York.

Time Signals. — The attention of the public has been directed to this department of our work by the introduction of the new system of standard time. The policy of this Observatory, with regard to the change, has been to avoid taking any action tending to force it upon the public against their wishes, but to point out, and so far as possible to avert the difficulties that would arise should two systems of public time remain in general use. An early decision was required, since the railroads centring in Boston made their assent to the change conditional on the adoption of the new time in dropping the Boston time-ball. Action was delayed, however, until the official assent of the city of Boston had been given to the adoption of the new time for striking the hour-bells and for the public clocks. The unanimity and ease with which the community adopted the new time was largely due to the activity of Mr. Edmands, Assistant in Charge of the Time Service.

It is probable that the use of our signals will soon be extended by the introduction of new devices. The Rhode Island Electric Company and the New England Telephone and Telegraph Company are now receiving our signals without charge while they conduct experiments with this view.

The Boston time-ball was dropped on 361 days, at noon, — on 321 days by telegraph, and on 40 days by hand. On four days it failed to drop at noon, but was dropped five minutes later, — on three days by telegraph and on one day by hand, — according to the usual arrangement. On December 6, 1882, the ball was dropped at 8 h. 30 m. A.M., and at 4 h. 0 m., P.M., as well as at noon, for the benefit of those desirous of making exact observations of the transit of Venus.

Telegraphic Announcements. — The system of announcing astronomical discoveries employed here for some years past has received an important extension during the last year. An association of over fifty European observatories has been formed, with its headquarters at Kiel, for the purpose of expediting the announcement of astronomical discoveries. The Smithsonian Institution, which had for many years rendered an important service to astronomy by transmitting astronomical telegrams between Europe and America, courteously signified its readiness to transfer this function to the Observatory of Harvard College, upon learning that this Observatory was prepared to undertake it. The change was announced by a circular issued by the Smithsonian Institution on January 10, 1883, and since that time the Observatory has distributed in this country the astronomical intelligence received from the European association, and has forwarded to Kiel information of American discoveries.

The Observatory is fortunate in having secured the assistance of Mr. John Ritchie to take charge of this department of its work.

Both Messrs. Chandler and Ritchie, by whom the present system of telegraphing astronomical announcements was devised and carried into effect, are therefore now included in the corps of the Observatory.

The early transmission by telegraph of observations and computed elements of comets between this observatory and that of Lord Crawford at Dun Echt is continued as in former years. The similar interchange of information with Dr. Oppenheim of Berlin is likewise maintained. The intelligence thus transmitted is distributed in Europe and here by means of special circulars.

Transit of Venus, 1882. — For reasons stated in the last Report, no elaborate preparations were made at this Observatory for observing the transit of Venus on the sixth of last December. But as the weather was favorable during most of the day, a considerable number of observations was obtained. Six telescopes were employed in observing the contacts. With the large equatorial, photometric and spectroscopic observations were also undertaken. The photometric measures furnished the result that the relative light of the Sun and Venus was in the ratio of 100 to 1.6, while the light of the sky surrounding the Sun would be expressed on the same scale by 7.5. This comparative darkness of Venus with respect to the sky was confirmed by direct observation. The spectroscope furnished no evidence of an atmosphere surrounding Venus ; but the dispersion employed was not large.

The diameter of Venus was carefully determined by Professor Rogers and Mr. Chandler, with the results 16″.09 and 16″.35. The method employed was that of transits over inclined lines. An account of all these observations appears in the Proceedings of the American Academy of Arts and Sciences, XVIII. 15.

Almucantar. — An interesting series of observations has been made by Mr. Chandler to test the merits of an instrument devised by him some years ago. It consists essentially of a telescope floating upon mercury, and is designed for the observation of transits over given parallels of altitude. Its name has been derived from this circumstance. This instrument, although having an objective of only 1¾ inches aperture, has given results of a high degree of accuracy, the probable error of a single determination of zenith distance being 0.″5 to 0.″6. Mr. Chandler is now directing the construction of a large instrument of the same kind with a telescope five inches in aperture, and intends to apply it to certain important problems in practical astronomy, for the solution of which it possesses advantages over other astronomical instruments.

While passing last summer in Europe, I visited the observatories at Greenwich, Oxford, Cambridge, Paris, Brussels, Bonn, Strasburg, Berne, Geneva, Milan, Vienna, Berlin, and Potsdam, and the private observatories of Dr. Huggins, of Mr. Common, and of Mr. Ranyard. I was also enabled to present some of the results of work in progress here at meetings of the Royal Astronomical Society at London, the Astronomische Gesellschaft at Vienna, and the Liverpool Astronomical Society. The most important result of my journey was the acquisition of copies of some valuable unpublished manuscripts. By the courtesy of Lady Herschel and of Lieutenant-Colonel John Herschel, I was permitted to examine the original manuscripts of Sir William Herschel's observations of the light of the stars. This led to the discovery of two unpublished catalogues, of which I was allowed to make a copy. The reduction of the four published catalogues by means of our photometric measures has already been mentioned in my last Report. The two additional catalogues furnish means for completing this work, so that we have now a most valuable determination of the light of all the stars in Flamsteed's Catalogue at a time when no other estimates of their light are known to exist. By the kindness of Professor Schönfeld, Director of the Bonn Observatory, I was permitted to make a copy of the unpublished observations of variable stars made by the late Professor Argelander after the publication of Volume VII. of the Bonn Annals. These manuscripts will be very valuable in connection with the bibliography to which reference has already been made.

PUBLICATIONS.

The printing of Volume XIV. of the Observatory Annals has gone on steadily during the year, the printers having constantly been supplied with copy.

The publications named below have appeared since the similar list in the last Report was drawn up, either as official communications from the Observatory, or as papers prepared by its officers individually.

Thirty-seventh Annual Report.

Statement of work done at the Harvard College Observatory during the years 1877–82. By Edward C. Pickering. Cambridge, 1882.

First Circular of Instructions for Observers of Variable Stars, acting in co-operation with the Harvard College Observatory, dated January 27, 1883.

Circulars relative to the Collection and Distribution of Astronomical Intelligence. Cambridge, 1883.

On the Telegraphic Transmission of Astronomical Data. Part ii. The Phrase Code.

Circular on Astronomical Photography, dated February 21, 1883.

Address by Professor Pickering at the June Meeting of the Royal Astronomical Society. The Observatory, vi. 199. Astronomical Register, xxi. 150.

Address by Professor Pickering at the Second Annual General Meeting of the Liverpool Astronomical Society. Abstract of Proceedings, 2. Astronomical Register, xxi. 278.

The Wedge Photometer. By Edward C. Pickering. Proc. Am. Acad. of Arts and Sciences, xvii. 231.

Observations of the Transit of Venus, December 5 and 6, 1882, made at the Harvard College Observatory. Edward C. Pickering, Director. Id. xviii. 15.

On a Method of determining the Index Error of a Meridian Circle at any Instant, depending upon the observed Polar Distance of Polaris. By W. A. Rogers. Id. xviii. 284.

Studies in Metrology. By W. A. Rogers. Id. xviii. 287.

On the Reduction of Different Star Catalogues to a Common System. By W. A. Rogers. Id. xviii. 399; Astronomische Nachrichten, cvi. 257.

A Study of the Centimeter marked "A," prepared by the U. S. Bureau of Weights and Measures for the Committee on Micrometry. By W. A. Rogers. Proc. Am. Soc. of Microscopists, 1883, p. 184.

A Critical Study of the Action of a Diamond in ruling Lines upon Glass and Metals. By W. A. Rogers. Id. p. 149.

Note on Probable Errors. By W. A. Rogers. Id.

Vice-President's Address on the German Survey of the Northern Heavens. By W. A. Rogers. Proc. Am. Assoc. for the Advancement of Science, 1883, p. 53.

Results of Tests with the Almucantar in Time and *Latitude*. By S. C. Chandler, Jr. Id. (Also Sidereal Messenger, ii. 269.)

Mountain Observatories. By Edward C. Pickering. Appalachia, iii. 99. The Observatory, vi. 287.

On the Orbit of the Great Comet. By S. C. Chandler, Jr. Astronomische Nachrichten, ciii. 347.

On the Orbit of the Great Comet. By S. C. Chandler, Jr. Id. ciii. 381.

Elements of Comet 1882, I. By O. C. Wendell. Id. civ. 287.

Elements and Observations of the Comet 1883, Brooks-Swift. By S. C. Chandler, Jr. Id. cv. 127.

Ephemeris of Comet 1883, Brooks-Swift. By John Ritchie, Jr. Id. cv. 143.

On the Variability of 36 (Uran. Argentina) Ceti. By S. C. Chandler, Jr. Id. cv. 333.

New Planetary Nebulae. By Edward C. Pickering. Id. cv. 335.

Erratum in the Position of a Variable Star. By Edward C. Pickering. Id. cv. 351.

Observations of Comet 1883, I. (Brooks-Swift) at Harvard College Observatory. By S. C. Chandler, Jr. Id. cvi. 9.

A convenient Method of finding or identifying an Asteroid. By O. C. Wendell. Id. cvi. 205.

Date of Discovery by Brooks of Pons' Comet. By John Ritchie, Jr. Id. cvii. 43.

On the Outburst in the Light of the Comet Pons-Brooks, September 21–23. By S. C. Chandler, Jr. Id. cvii. 131.

It is evident that the present rapid accumulation of results will soon involve an important question regarding their publication. The funds especially provided for this purpose will prove entirely inadequate, and the application to this purpose of the unrestricted funds of the Observatory must be considered. This subject will probably be more fully treated in my next Annual Report.

EDWARD C. PICKERING, *Director.*

THIRTY-NINTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE DECEMBER 17, 1884, AND
LAID BEFORE THE BOARD OF OVERSEERS, JANUARY 14, 1885.

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REPORT.

To the President of the University:

Sir, — The termination of the annual subscription in aid of the Observatory and its partial replacement by the income of a recently subscribed endowment, were mentioned in my last report. The amount of the temporary subscription somewhat exceeded the annual sum of $5,000. Moreover many of the contributors paid their subscriptions for the whole term of five years soon after making them, thus enlarging their donations by a considerable amount of interest since accumulated in the hands of the College Treasurer. The expiration of the subscription, therefore, did not immediately produce its full effect in diminishing the available resources of the Observatory. But the time has now arrived when a considerable restriction of scientific work appears to be inevitable. The recently subscribed endowment, indeed, will permit the continuance of some important researches undertaken during the past five years, which without it must now have been laid aside. Still the decrease during the last ten years in the rate of interest yielded by the funds of the University is so great that the income of the new endowment of $50,000 does not fully replace the diminution in that received from the older endowments. For the ten years ending in 1876 the average rate of interest was 7.21 per cent, while for the last year it has been only 5.17 per cent. The new endowment must therefore have been as much as $70,000 to prevent a reduction in the resources of the Observatory.

The liberal response of the friends of astronomy in this neighborhood to former appeals for assistance prevents a further demand upon their generosity at the present time. The alternative of a reduction in the expenses of the Observatory must therefore be accepted. It has accordingly been found necessary to dispense with the services of five assistants, and to make a corresponding decrease in expenditures of other kinds. The retirement of so many assistants is particularly unfortunate, since the special skill which they had gained in their departments of work by the experience of several years will now be lost to the Observatory. At the same time they will be subjected to the inconvenience of adapting themselves to other pursuits, after having devoted much time and labor to the attainment of their present proficiency in the principal kinds of observation and computation which are required by the researches here pursued.

The place of one assistant has fortunately been supplied without expense to the Observatory by the courtesy of Commodore Walker of the U. S. Navy. He has ordered Ensign E. E. Hayden to duty at this institution, to assist in the work carried on with the Meridian Circle. This arrangement, it is believed, will result in mutual benefit, since an opportunity of acquiring skill in advanced scientific work is thus afforded to an officer of the Navy, while the Observatory enjoys the advantage of the excellent preparation for such work resulting from his previous education and experience.

It is to be hoped that the present restriction of the activity of the Observatory may prove to be only temporary, through the continued addition of unsolicited donations. An important bequest of $5,000 has been received during the past year from the estate of the late Thomas G. Appleton, who has thus given a further evidence of the interest which he showed in the Observatory during his life. The gift of £25 received from Mr. T. W. Backhouse of Sunderland, England, as a contribution to the subscribed endowment, also demands special acknowledgment, since it indicates that the interest taken in the welfare of this Observatory extends beyond its immediate vicinity.

Many valuable additions have been made by astronomers in this country and in Europe to the collection of astronomical photographs undertaken last year. It is hoped that before long a catalogue of the collection may be prepared.

EAST EQUATORIAL.

Eclipses of Jupiter's Satellites. — Photometric observations of these eclipses have been continued upon the system adopted in 1878. In all, two hundred and eighty-four eclipses have now been observed, forty-seven since the end of October, 1883.

Revision of Zone Observations. — The revision of the observations given in Volume VI. of the Annals of this Observatory, so far as they relate to stars between 50′ and 60′ north of the equator, has been completed during the last year. Some discrepancies in position and magnitude have been found which cannot readily be explained by errors in the observations. The stars thus indicated as interesting objects for further examination will be reobserved.

Standards of Stellar Magnitude. — The charts of twenty-four regions extending 4^m in right ascension and 10′ in declination, and following a series of twenty-four bright stars, as described in the last report, have now been completed. Valuable assistance in revising these charts has been received from Professor E. S. Holden, Director of the Washburn Observatory, Madison, Wisconsin. The telescope of the Washburn Observatory has a slightly larger aperture than that at this Observatory. Similar assistance has been promised by some other observers with still larger telescopes.

Meanwhile the selection of stars for standards of stellar magnitude has been made for many of the regions thus charted, and photometric measurements of their light have been begun. The brighter stars of each region are within the reach of the meridian photometer. To connect these with others of the tenth and eleventh magnitudes the modified wedge photometer is employed in nearly the same manner as in the revision of the zone observations already mentioned. With the addition of a simple shade-glass, stars of the second magnitude may be observed with this wedge, and a further connection is thus made between its work and that of the meridian photometer. The stars in each region which are too faint for observation with the wedge are compared with the bright star, preceding the region under examination, by means of Photometer I, described in Volume XI. of the Annals of the Observatory. Many of the stars observed with the wedge can also be measured with Photometer I, and all the results of the work may thus ultimately be referred to the meridian photometer. Additional photometric methods of measurement are under consideration and it is hoped that the magnitudes of the standard stars which are selected in each region will be determined with a satisfactory precision by these investigations.

Comets. — The observation of comets has been continued by Mr. Wendell with the object of furnishing material for the early computation of their orbits and of providing means for subsequent determinations of greater accuracy. The observations therefore are chiefly confined to the few days following the discovery of a comet and to occasions when it is too faint to be observed with any but powerful telescopes. Comets 1884 I., II., and III. were respectively observed on 6, 6, and 7 nights.

Spectra and Color of Stars. — Two separate series of investigations with regard to stellar spectra have been undertaken. It has been proposed to examine all stars known to have banded spectra with the object of approximately determining the positions of the bands in each upon a uniform system. This would afford means for a more definite and satisfactory classification of these spectra than at present exists. The method of measurement consists in comparing the spectrum with a notched bar beside which it is placed in the field of the telescope. The proper position of the spectrum is secured by a previous reference to an image of the star formed by light allowed to pass beside the prism which forms the spectrum.

For the acquisition of more definite knowledge than at present exists with regard to the color of stars, it has also been proposed to observe all stars to the fourth magnitude inclusive, and north of the thirtieth parallel of south declination, with an instrument designed for the purpose. The spectrum of the star to be observed is properly placed in the field by the same means as in the other instrument just described. It is then carried by its diurnal motion behind a series of narrow bars placed at right angles to the spectrum, small portions of which are accordingly visible in the narrow spaces between the bars. The successive extinction of these portions of the spectrum is observed in a wedge of tinted glass. In this manner the relative brightness of definite parts of different spectra may be compared.

The diminished resources of the Observatory will probably not permit the completion of these observations upon the original plan. The observations relating to the banded spectra must be somewhat restricted, and those relating to the color of the stars must be confined to stars of the first three magnitudes.

Revision of DM. Magnitudes. — The meridian photometer permits the observation of stars as faint as the magnitude 9.0 and even somewhat fainter. But for the observation of the faintest stars in the Durchmusterung a more powerful instrument is preferable. The modified wedge photometer used with the East Equatorial in the revision of the zone observations already mentioned has accordingly been applied to the observation of the zone between 49° 50′ and 50° 0′ north of the equator. This zone is a part of that which has been observed here since 1870 with the meridian circle, for the determination of the positions of stars. It is also under observation with the meridian photometer, which will accordingly furnish points of reference for the observations made with the wedge photometer applied to the equatorial. Each star belonging to the zone and occurring in the Durchmusterung is twice observed, on different nights, and the interval between its transit over a bar and its disappearance in the wedge is recorded. This work can be carried on by a single observer, although some time is saved by the assistance of a recorder when it can be had. If the results prove satisfactory a more extensive revision of the magnitudes given by the Durchmusterung will be undertaken in the same way.

MERIDIAN CIRCLE.

The observation of fundamental stars has been continued throughout the year, but with less regularity than during former years on account of the interruption caused by the reobservation of scattering zone stars of the Durchmusterung list. During the Autumn Equinox of 1883, 604 observations of fundamental stars were made. The Sun was observed on 34 days, and Polaris on 26 days. During the Spring Equinox of 1884 the Sun was observed on 33 days, Polaris on 30 days, and 261 observations of fundamental stars were obtained. At other times during the year the Sun was observed 46 times, Polaris 59 times, and 301 observations of fundamental stars were made.

At the completion of the reduction of the zone stars, observed between 1870 and 1879, it was found that about 400 stars required further observation. In the greater number of cases it was found that the wrong star had been observed when two or more were in the same field of the telescope. In other cases it was considered advisable to settle doubtful cases, especially with regard to the minute of declination, by a reobservation. This revision of the zone observations was begun October 9, 1883, and was completed August 9, 1884. 1463 observations were made of zone stars, and 671 corresponding fundamental stars were observed in addition to the observations enumerated above. It will be seen from this summary that the total number of observations made with the meridian circle is 3528, and does not materially vary from the number in former years.

The investigation of the errors of the east circle has occupied a large portion of the time since July of the present year. Eighteen determinations of the stars of the 30° divisions of the circle have been made with very satisfactory results. Two independent determinations of the 15° divisions have also been made. It is proposed to continue the investigation of the main subdivisions of the circle at regular intervals throughout the coming year. This work will for the most part oc upy the entire time of Professor Rogers for several months, and will take the place of the ordinary observations. During the year considerable progress has been made in printing Volume XV. The catalogue of all the primary and secondary stars observed between 1870 and 1879 for the epoch 1875.0, together with the mean values of the coördinates of each star for each year of observation, is printed, and will shortly be issued in advance of the publication of the entire volume. The reductions of the zone stars observed during the past year are about one half completed.

MERIDIAN PHOTOMETER.

During the past year 141 series of observations have been taken with the meridian photometer by Mr. Wendell and myself. The total number of separate settings is about 27,500, an increase of more than a third over the previous year. The accordance of the results also shows a decided improvement in the accuracy of the measures. The average deviation of the separate measures of the one hundred circumpolar stars to which all the others are referred, amounted to about .18 of a magnitude with the first meridian photometer. The new instrument gives .15, .12 and .11 for the same quantity in the three years in which it has been employed. Since the value of the observations is proportional to the squares of these quantities, it appears that one of our present observations is nearly equal to three with the smaller instrument employed in the observations which have been published in Volume XIV.

The principal investigation now carried on with the meridian photometer consists in the measurement of stars the magnitude of which has been estimated at each of two observations during the recent revision of the Durchmusterung. The number of such stars is about eight thousand. Besides the two estimates just mentioned, two others were made in the original formation of the Durchmusterung, and additional estimates for many of the stars also occur in other catalogues. The results obtained by the meridian photometer will therefore have a wide application in the determination of scales of magnitude. In connection with the photometric observations, estimates of magnitude are made by the observers.

Another class of stars observed with the meridian photometer comprises a part of those already measured with the smaller instrument of the same kind employed here during the years 1879 to 1883. The stars selected for remeasurement are those for which the magnitude resulting from any single observation differed more than 0.5 from the mean of the other results. All stars belonging to Flamsteed's British Catalogue, and not already measured with the first meridian photometer, are likewise observed with the new intrument. These observations will serve to complete the reduction of the comparisons made by Sir William Herschel. Other observations made with the meridian photometer relate to asteroids, to known and suspected variables, to stars with peculiar spectra, and to objects having any special characters which may make it a matter of interest that their light should be measured.

MISCELLANEOUS.

Almucantar.—It was mentioned in the last report that a small instrument bearing this name and devised by Mr. Chandler had been employed by him with very satisfactory results in the observation of transits over given parallels of altitude. He accordingly decided upon the construction of an instrument of the same kind and sufficiently large for the execution of researches similar in importance and delicacy to those usually undertaken with the best meridian instruments. The telescope of this large almucantar is 4 inches in aperture and 43.8 inches in focal length. The frame to which it is attached floats in a shallow trough of mercury, as in the previous instrument, and the entire apparatus revolves upon a vertical axis. Various difficulties which occurred in its construction were removed by the ingenuity of the inventor, and it was mounted during April, 1884. After about a month of experimental observations it was applied to the determination of the corrections required by the right ascensions of certain fundamental stars near the pole, and the declinations of others near the equator. It is hoped that the results of this investigation will establish the value of the new principles of construction and of observation employed in the undertaking. Up to November 1, about 700 observations of 190 stars had been made. Many additional observations have been made for other purposes; in particular, the determinations of clock error required by the time service of the Observatory have been frequently made by the almucantar.

The results thus far secured seem to justify the expectations entertained of the capacity of the almucantar to determine with exactness the relative positions of stars widely separated from each other. It will be useful, accordingly, not only in observations of time and latitude but also in various higher and more delicate problems of practical astronomy, for the solution of which it furnishes a new method.

The probable error of a single observation of zenith distance is in general ± 0.″37, and of a single observation of right ascension ± 0.^{s}025. Certain minor improvements in the apparatus, now under consideration, are expected to afford a still further increase in accuracy.

The latitude of the dome of the Observatory given by three nights' work with the new almucantar is 42° 22′ 47.″58 ± 0.″09, which closely agrees with the value 42° 22′ 47.″63 found last year by the small almucantar.

The character of the various results given above encourages the hope that the use of the almucantar may become a permanent part of the work done at this Observatory. Should the results prove no more accordant than those of other instruments, the fact that they are obtained by an entirely independent method would free them from many of the errors which are commonly repeated in meridian observations.

Variable Stars. — The observation of telescopic variables was continued by Mr. Chandler upon the same system as before until May, since which time he has been chiefly occupied with the almucantar. He obtained 1240 observations of the light of variable stars between November 1 and June 30. He also made 952 observations of the color of 108 variable stars. The color was generally estimated upon an arbitrary scale, but many determinations were also made by the estimation of magnitudes with and without the use of a blue shade glass. The results of this work seem to establish the law that the redness of variable stars increases with the length of their periods.

Three observers of variable stars have acted in coöperation with this Observatory during the past year: Mr. H. M. Parkhurst, of New York, Rev. J. Hagen, S. J., of Prairie du Chien, Wisconsin, and Mr. J. H. Eadie, of Bayonne, N. J. Mr. Parkhurst, in addition to estimates of relative brightness, has made many photometric observations with apparatus devised by himself. He has recently undertaken the observation of the comparison stars employed for several variables by previous observers. Father Hagen, assisted by Messrs. Zwack and Zaiser, besides observing many known variables, has examined a number of bright stars suspected of variability. Mr. Eadie is acting in special coöperation with Mr. Parkhurst, in such a manner as to obtain the best results without needless repetition of work. The labors of all these gentlemen have secured a large amount of valuable knowledge.

Under the title "Recent Observations of Variable Stars" (Proc. Amer. Acad. XIX. 296) information was brought together for the guidance of observers in that branch of astronomy with regard to the selection of objects for observation. The pamphlet contains a list of variable stars, with indications of the work recently done in observing them, so that the relative importance of further observations of any object in the list may be apparent. The publication will be continued annually if it appears to meet a want among astronomers, and if they comply with the request expressed in the pamphlet to forward to the Observatory such notices of their observations of variable stars as may serve to render the list more complete.

Time Signals. — The new standard time referred to in my last report was introduced in November, 1883. At Greenwich midnight on the seventeenth of that month the signals according to the meridian of the Boston State House were discontinued; at the next Greenwich noon signals over our lines were sent conforming to the minute and second of Greenwich mean time; and at mean noon on the seventy-fifth meridian on Sunday the eighteenth, the Boston time-ball was dropped according to Eastern time, five hours slow of Greenwich mean time.

The office of the U. S. Signal Service having been moved on October 1, 1884, from the Equitable building to the Boston Post-Office and Sub-Treasury building, the time-ball has been dropped since that date by an officer detailed by the Police Commissioners. A new ball, however, is to be erected on the Post Office building to be dropped by the Signal Office. The public has been much indebted to the management of the Equitable Life Assurance Company for accommodating the ball upon the roof of their building and for furnishing and maintaining the apparatus used there.

Several companies having recently begun operations for distributing time by electric clocks and by striking the hour and minute to the listener at a telephone, our time has been furnished them during their experimental steps either gratuitously or for a small compensation. The Observatory however has not been responsible for ascertaining that the companies have furnished their patrons with time conforming to the standard. Negotiations are pending for a more intimate connection of one or more of these enterprises with us. The Western Union Telegraph Co. have received our signals and have been permitted to transmit them automatically to others. The following list comprises those who receive our time for regulating their time-pieces and similar purposes, but who are not authorized to directly transmit or automatically repeat the signals to others: American Watch Co., C. W. Beals, Bigelow, Kennard & Co., Wm. Bond & Son, Boston Electric Time Co., C. A. W. Crosby, Equitable Life Assurance Co., E. Howard & Co., Kattelle Bros., J. V. Kettell & Co., Geo. H. Morrill & Co., Jas. Munroe & Son, N. E. Telegraph and Telephone Co., G. H. Richards, Jr., R. I. Electric Co., Shreve, Crump & Low, Alvah Skinner & Son, Ira P. Stere & Co., U. S. Signal Service Office. The large subscribers, on whom depends the existence of the time service as now conducted, are the city of Boston and all the steam railroads having stations in Boston, except the Boston & Lowell R. R. and the Revere Beach R. R.

Telegraphic Announcements. — This department of the work of the Observatory is conducted by Mr. Ritchie upon the enlarged system mentioned in the last report. During the year announcements have been sent to thirty institutions or individuals in this country. The total number of messages is 246, of which 107 related to asteroids, 119 to comets, and 20 to the elements of cometary orbits. The number of asteroids discovered was nine, but with regard to one of these discoveries no telegraphic information was received from Europe. The number of comets discovered was four. All the notices were distributed by means of the Associated Press and the local newspapers, as well as by telegraph. The "Science Observer" also issued thirteen special circulars relating to the various announcements.

PUBLICATIONS.

The chief publication of the Observatory during the past year has been Volume XIV., Part I. of its Annals. This gives the principal results of the work done with the first meridian photometer. It includes a catalogue of 4,260 stars with their magnitudes as determined by the photometer and according to the estimates or measures of seventeen other authorities. As uniformity in reference to catalogues is always desirable, it has been suggested in the volume that this catalogue should be known as the "Harvard Photometry" and designated by the abbreviation H. P. Since it contains the approximate places for 1880 of all stars visible to the unaided eye in this latitude, as well as their magnitudes, its principal columns have been separately reprinted and offered for sale at the cost of publication, under the title of Harvard Photometry. The stereotype plates of this portion of the catalogue will be preserved, so that additional copies may be printed at any time when they may be needed.

The second part of Volume XIV. is now in course of publication. It contains the discussion of many special topics connected with the photometric observations recorded in the first part of the volume, and with the corresponding estimates or measures of other observers since the time of Ptolemy.

The publications named below have appeared since the similar list in the last report was drawn up, either as official communications from the Observatory or as papers prepared by its officers individually: —

Thirty-eighth Annual Report of the Astronomical Observatory of Harvard College.

On the Possible Connection of the Comet Pons-Brooks with a Meteor-stream. By S. C. Chandler, Jr. Astronomische Nachrichten, cvii. 275.

Observations and Ephemeris of U Ophiuchi. By S. C. Chandler, Jr. Id. cviii. 55.

Observations of Meteors, 1883, December 6. By O. C. Wendell. Id. cviii. 433.

Elements and Ephemeris of Comet 1884 II. By S. C. Chandler, Jr. Id. cix. 223.

On a Convenient Formula for Differential Refraction in Ring-micrometer Observations. By S. C. Chandler, Jr. Id. cx. 177.

On Gegenschein and other Zodiacal Phenomena. By Arthur Searle. Id. cix. 257.

The Zodiacal Light. By Arthur Searle. Proc. Am. Acad. of Arts and Sciences, xix. 146.

Researches upon the Photography of Planetary and Stellar Spectra. By the late Henry Draper. Results of Measurements by E. C. Pickering. Id. xix. 231.

Sir William Herschel's Observations of Variable Stars. By Edward C. Pickering. Id. xix. 269. The Observatory, vii. 256.

Recent Observations of Variable Stars. By Edward C. Pickering. Proc. Am. Acad. of Arts and Sciences, xix. 296.

The Phases of the Moon. By Arthur Searle. Id. xix. 310.

Report of the Committee on Standard Time (Wolcott Gibbs, Francis A. Walker, and J. Rayner Edmands). Id. xix. 473.

Photometric Observations of Neptune at the Harvard College Observatory. By Edward C. Pickering. The Observatory, vii. 134.

Light of Comparison Stars for Vesta. By Edward C. Pickering. Am. Journal of Science, cxxviii. 17.

Second Report of the Committee on Standards of Stellar Magnitudes. Edward C. Pickering, Chairman. Proc. Am. Assoc. for the Advancement of Science, 1883, p. 1.

On the Regraduation of the Harvard College Meridian Circle *in situ*. By William A. Rogers. Sidereal Messenger for December, 1884.

On a Practical Solution of the Perfect Screw Problem. By William A. Rogers. Transactions of the American Society of Mechanical Engineers. Vol. V.

On some Suspected Variable Stars. By S. C. Chandler, Jr. Science Observer, IV. 60.

Elements and Ephemeris of Comet 1884 II. (Barnard). By S. C. Chandler, Jr. Science Observer, IV. 80.

EDWARD C. PICKERING, *Director*.

FORTIETH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

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1 FEB. 3
OXFORD

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE DECEMBER 3, 1885, AND
LAID BEFORE THE BOARD OF OVERSEERS, JANUARY 13, 1886.

CAMBRIDGE, MASS.
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1886.

REPORT.

To the President of the University:

Sir, — By the death of Mr. Robert Treat Paine during the past year the Observatory of Harvard College has lost one of the oldest of its friends, well acquainted with the theory and practice of several departments of astronomy, and always deeply interested in the work of this institution. He was an assiduous computer and observer of astronomical and meteorological phenomena, and a member of the Visiting Committee of the Observatory from the time of its first organization, forty years ago. He has perpetuated his services to his favorite science by the bequest to this Observatory of his entire fortune, amounting to more than a quarter of a million of dollars. Upon the settlement of the estate, one half of this sum will become immediately available.

The resignation of another of the original members of the Visiting Committee, Mr. J. Ingersoll Bowditch, is a matter of extreme regret. His services to the Observatory have been continuous, and without his active aid and advice no important steps have been taken in the extension of its work, which has frequently been rendered possible only by his exertions.

During the year the work of which is to be described in the following paragraphs, the resources of the Observatory have been materially diminished, owing to circumstances stated in the last report. It was there mentioned that no means were available for retaining the services of five of the assistants previously employed. But the salary of one of these assistants for another year was soon after provided by means of a subscription undertaken by some of his colleagues, who furnished a part of the required sum from their own scanty means. Without this relief, it would have become necessary to interrupt the regular use of the large telescope in order to continue work with the meridian instruments. As it is, the reduction in the amount of work carried on is much less than would have been expected; but this result is due to extraordinary efforts on the part of the observers, who have performed without assistance the work in which they were previously aided by recorders. This has required an increase in the time spent in observation, and has rendered the work much more laborious. While this evidence of enthusiasm and devotion to science is most gratifying, it is obvious that it cannot long be continued without injury to health. Indeed, the effects of over-fatigue and exposure during the long, cold nights of last winter were manifest in more than one instance.

EAST EQUATORIAL.

Eclipses of Jupiter's Satellites. — Photometric observations of these eclipses have been continued upon the system adopted in 1878. In all, three hundred and nineteen eclipses have now been observed, thirty-five since the end of October, 1884. The original plan contemplated the prosecution of the work through an entire revolution of Jupiter around the Sun, more than half of which has already been completed. The importance and extent of this work has made it advisable to delay the adoption of a definite plan of reduction until a sufficient amount of experience had been gained; but there is now no reason to defer the consideration of this subject.

Revision of Zone Observations. — The reduction of the observations of the stars between the declinations + 0° 50′ and + 1° 0′ has been carried on. To determine the scale of the wedge photometer employed in the work, the constants of the instrument have been photometrically examined, and the initial point of the scale for each evening of observation has been determined by means of the stars in each series which also occur in the working list of the meridian photometer. In the entire zone there are about three hundred such stars, all of which have now been measured with the meridian photometer. The magnitudes of the fainter stars observed in the zone with the wedge photometer have been recomputed by the aid of these data. The work of the wedge has thus been made homogeneous with that of the meridian photometer.

Revision of DM. Magnitudes. — The observations of DM. stars between the declinations + 49° 50′ and + 50° 0′, which were begun with the wedge photometer during the previous year, have been completed, as well as a similar series between + 54° 50′ and 55° 0′. The resulting magnitudes have been computed, as in the case of the zone between + 0° 50′ and + 1° 0′, by means of the stars occurring in these zones which are also under observation with the meridian photometer. It is desirable that similar observations should be made in other zones at intervals of 10°. This would extend the scale of the meridian photometer about one magnitude, and would furnish means for determining the scale of the Durchmusterung between the magnitudes 9.0 and 9.5.

The extensive use thus made of the wedge photometer seems to show that the instrument used here is not capable of the great degree of precision which is claimed for that employed by Professor Pritchard. To determine whether this difference is due to the form of the instrument, Professor Pritchard was requested and has kindly consented to superintend the construction for this Observatory of a wedge photometer made upon his plan.

Standards of Stellar Magnitudes. — The photometric observations of faint stars selected as standards of magnitude in twenty-four regions following bright stars, and mentioned in previous reports, have been provisionally completed. A few of these stars were bright enough to be observed with the meridian photometer; but most of them were observed with the East Equatorial, with the aid of the wedge photometer or of Photometer I. The results have been published in the report to the American Association for the Advancement of Science by the committee in charge of the subject of stellar magnitudes.

Comparison Stars for Variables. — Another extensive investigation begun with the wedge photometer is the determination of the magnitudes of stars which have been used as standards of comparison for variable stars. Besides the stars of this class named in published works, many others, employed in observations not yet published, have been added to the list. Observers of variable stars are requested to communicate to this Observatory the comparison stars employed by them, and not identical with those contained in published lists. When these comparison stars are sufficiently bright, they are measured by the meridian photometer. Their magnitudes, thus determined, serve as a basis for the measurement of the fainter stars by the wedge. Two observations of each star not determined by the meridian photometer, and of a sufficient number of the others, are made with the wedge on each evening when the region occupied by the comparison stars of any particular variable is observed. Two complete observations of this kind, made on different evenings, are regarded as sufficient; but when moonlight or other causes render the work of either evening imperfect, it is repeated on a third evening. Some incidental attention is also paid, during this work, to enlarging the lists of comparison stars when they can thus be better adapted for future use.

Temporary Star in the Nebula of Andromeda. — This remarkable object, as well as a series of comparison stars selected for it, was repeatedly observed with the wedge photometer immediately after the announcement of its discovery. It is still occasionally observed. It is proposed to determine photometrically the brightness of the stars with which it has been compared by observers at other stations, so far as these are made known.

Comets. — These objects have occasionally been observed as in former years, chiefly by Mr. Wendell. The observations have been confined to special times when they would be of most immediate value. Comet 1884 III. (Wolf) was observed on one night; two others, discovered by Barnard and by Brooks, were respectively observed on seven and on four nights.

Spectra and Color of Stars. — The observations upon the spectra and color of stars have been completed upon the restricted plan indicated in the last report, but are not as yet reduced. It is probable that photography will soon afford a more satisfactory solution of this problem. The work of the East Equatorial in this respect, and also in some others, has been considerably diminished during the year by the frequent employment of the observers in recording the observations made with the meridian photometer, since the diminished resources of the Observatory did not permit the engagement of special assistance in the work of recording.

MERIDIAN CIRCLE.

The work done with this instrument during the year has been more varied in character than usual, while its amount has been somewhat diminished by the financial necessity of dispensing with an assistant to the principal observer. A considerable portion of the year has been occupied with the investigation of the errors of the East Circle of the instrument. This work is now completed. The spaces of 30°, 15°, 5°, 1°, have been independently investigated; the labor thus performed is equivalent to that of reading a single microscope about forty thousand times.

In order to perfect the revision of the zone between +50° and +55°, some additional observations were found to be desirable, when the reduction of the preliminary revision, finished in August, 1884, had been completed. The doubts remaining to be settled chiefly related to possible errors of an entire minute in the circle readings, and to unusually large discrepancies between the positions here obtained and those given in the Durchmusterung. The new revision was begun January 8, 1885, and will be completed with six more nights of observation. Each star concerning which any doubt existed has ordinarily been twice observed. The whole number of observations is 937.

The observation of a polar catalogue was begun April 30, 1885. The working list includes 30 fundamental stars and 153 others. For the present year, the plan of the work requires two observations of each star at each culmination. The number of observations hitherto made is 384.

A series of 275 observations was carried on simultaneously with corresponding observations made with the almucantar, in order to compare the results given by the two instruments, and to test the precision of the Clark level attached to the meridian circle.

Observations of particular stars have also been made at the request of Dr. Auwers, Dr. Elkin, and Professor Holden. These observations are respectively 173, 24, and 12 in number. The first two series will furnish material for the determination of heliometer constants, and the last for the reduction of latitude observations.

The total number of observations with the meridian circle is accordingly 2808, including 1003 observations of fundamental stars employed in the revision of the zone and in the polar catalogue.

The reduction of the first revision of the zone observations is complete. The observations of fundamental stars made up to last October, during the second revision, are also reduced. The reduction of the miscellaneous observations is finished, with the exception of a few of those made at the request of Dr. Auwers.

The report of the longitude operations between Cambridge and Montreal in the summer of 1883 has been completed. It will appear, in connection with the report of Professor McLeod, in the forthcoming volume of the Proceedings of the Royal Society of Canada.

MERIDIAN PHOTOMETER.

The number of series of observations made during the year by Mr. Wendell and myself is 202, an increase of 61 over those of the previous year; and the number of separate settings somewhat exceeds 50,000, against 27,500 for the previous year. The accordance of the results continues satisfactory. The average deviation of the separate measures of the standard circumpolar stars, expressed in magnitude, is 0.12. Although this exceeds the corresponding result for the previous year by only a single hundredth of a magnitude, the difference may not be purely accidental, but have its cause in the variability of one or more of the standard stars.

The list of objects to be observed with the meridian photometer has been somewhat extended. The stars first selected from the Durchmusterung for observation were those the magnitude of which had been estimated at each of two observatories during the zone observations carried on during recent years under the general direction of the Astronomische Gesellschaft. To increase the regularity of distribution of the stars observed, other zones of 20′ in width were added, so that the entire series includes zones at intervals of five degrees from the equator to the pole. The middle of each zone is defined by the parallel of declination at 0°, + 5°, + 10°, etc.

This system ensured a regular distribution of the stars to be observed, and supplied a sufficient number of stars of the eighth and ninth magnitudes to be employed in the determination of the various scales of magnitude in use. The number of stars between the sixth and eighth magnitudes, however, hardly seemed large enough for this purpose. To supply the deficiency, the zones were extended to a width of 60′ for for stars of the magnitudes 7.0 to 7.9 inclusive, and to a width of 120′ for those of the magnitudes 6.1 to 6.9 inclusive. The magnitudes of the stars brighter than these have already been published in Volume XIV. of the Observatory Annals.

The miscellaneous work with the meridian photometer, mentioned in the last report, has been continued. Two special features of this work have already been mentioned in connection with the observations made with the wedge photometer.

Almucantar.

Mr. Chandler has continued his observations with this instrument, which in his hands has exhibited a surprising efficiency and accuracy, fully confirming the anticipations expressed in the last report. The work of observing was suspended after July 1, to allow time for the reduction of the previous observations, the number of which between November 1, 1884, and July 1, 1885, was approximately one thousand. The following subjects have been investigated: right ascensions of circumpolar stars; declinations of stars near the equator; the latitude of this Observatory; effects of personal equation at different declinations, obtained by observers with the meridian circle and with the almucantar. The positions obtained by means of the almucantar have such a precision as to have already led to the detection of errors in the accepted places of several important stars occurring in fundamental catalogues, and generally regarded as accurately determined.

Miscellaneous.

Variable Stars. — Messrs. Parkhurst, Eadie, Hagen, and Zaiser, have continued their valuable coöperation with this Observatory throughout the year. The large and rapidly increasing number of observations of variable stars secured by these gentlemen will form a highly important source of information with regard to such objects. Steps have been taken to provide for the reduction of these observations, which will require however the photometric determination of the brightness of the comparison stars before much progress in it can be made.

The request to astronomers made last year in the pamphlet "Recent Observations of Variable Stars" was kindly complied with by the principal observers of variable stars in Europe and America. Their names, together with a summary of their work, are given in the pamphlet "Observations of Variable Stars in 1884," which was published by this Observatory early in 1885.

Stellar Photography. — By the aid of the Bache Fund an important investigation has been undertaken in stellar photography. A Voigtlander portrait lens of 8 inches aperture and 44 inches focus has been reground and mounted equatorially by Messrs. Alvan Clark & Sons. It is driven by clockwork, having a Bond spring governor controlled electrically by a sidereal clock substantially mounted in the clock-room of the Observatory. A wide field of work is opened with this instrument. Many photographs have been taken of the trails left by a star when the telescope is not driven by clockwork. An equatorial star will leave its mark in this way when no brighter than the sixth magnitude. Much fainter polar stars will leave an impression, since their motion is slow. Stars as faint as the fourteenth magnitude have thus been photographed without clockwork. The positions of faint polar stars may be determined with great accuracy from their trails, which are very well defined and minute. They also appear to afford an excellent measure of stellar brightness. Attempts have also been made to prepare star-charts by photography. Regions 5° square will bear an enlargement of three times, and by photolithography will furnish charts of the dimensions and scale of those of Peters and Chacornac. The most striking results have been obtained with stellar spectra. Replacing the slit spectroscope by a large prism placed in front of the lens, photographs have been obtained of stars as faint as the eighth magnitude in which lines are shown with sufficient distinctness to be clearly seen in a paper positive. As all the stars in a large region are thus photographed, more than a hundred spectra have been obtained on a single plate. Mr. William H. Pickering has rendered important aid in this investigation, especially in the photographic process. A portion of Mr. Pickering's investigation on the possibility of photographing the solar corona without the aid of an eclipse was also conducted here. The conclusion thus reached was that, unless the effect of the air could be reduced three hundred times, no satisfactory results could be obtained with our present means. The details of this investigation will be found in *Science* VI., 362, 387.

Time Signals. — The time service of the Observatory has not fully succeeded at all times during the year in maintaining the high standard of former years. Inevitable interruptions and delays have occurred from various causes, among which may be specially mentioned the want of a duplicate mean time clock and the increasing number of telephone and telegraph wires used in Boston, with its natural consequence of frequent interference with wires previously in use. By persevering exertion, however, a satisfactory system for transmitting the signals has now been established. Much delay also occurred in making the arrangements necessary for the new time-ball, which was not brought into operation until October 1, since which time it has been regularly dropped. It is made upon the plan adopted by the United States Government offices, and its cost has been largely provided for by an appropriation made by the city government of Boston.

The list of subscribers to the time signals remains nearly the same as that given in the last report, the most important accession being that of the Boston and Lowell Railroad.

Telegraphic Announcements. — The telegraphic distribution of important astronomical discoveries or data has been continued during the year under the management of Mr. Ritchie, as before. Announcements have been made of the discovery of nine asteroids, five comets or suspected comets, and one new star. There have been sent to Europe or received therefrom twenty cable messages, and the number of telegrams sent in this country was two hundred and seventy. The Associated Press has been regularly notified of the facts thus distributed, and the information has been widely spread by means of the newspapers.

Height and Velocity of Clouds. — This subject has been studied during the year by Professor W. M. Davis, assisted by Mr. A. McAdie, who stationed themselves respectively on the east balcony of the Observatory and at the Jefferson Physical Laboratory. These stations were connected by telephone, and the observers were thus enabled to decide upon suitable portions of clouds for simultaneous observation with wooden altazimuth instruments. About three hundred pairs of measures were made in the spring of 1885 with generally satisfactory results. The altitudes determined varied from 2000 to 25,000 feet; for altitudes less than 8000 feet the variation between the measures was generally within five per cent of the height. In one instance, consecutive observations of a single cumulus cloud showed its base to be 4500 feet high; its summit rose from the height of 6750 to that of 7300 feet at the rate of 200 feet a minute, while the cloud drifted to S. 43° E. at the rate of 27½ miles an hour.

Additional Researches. — Several investigations have been carried on by the aid of the Rumford Fund. They include the determination of the amount of light reflected specularly and diffusely by various substances at different angles; the absorption of the wedge of shade glass used as a photometer for the large equatorial; the opacity of a series of photographic images employed as standards by Mr. W. H. Pickering in his photographic researches. The atmospheric refraction at large zenith distances was determined by several series of observations of the Sun and of *α Bootis* when setting. Various measures were also made of the amount of the atmospheric polarization.

During the summer over a thousand vertical angles were measured from the summits of Mt. Moosilauk and of Mt. Mansfield to determine the heights of the mountains of New Hampshire and Vermont by the method of geodetic levelling.

For three quarters of an hour after the explosion of Flood Rock was expected to take place, Professor Rogers watched a mercury surface with a microscope to detect the effect of the earthquake wave. Disturbances occurred beginning $3^m 14^s$ after the explosion and lasting nearly three minutes, which were apparently due to this cause. Various experiments were afterwards made to show that no local disturbance could have produced the same effect. This appears to be far the greatest distance to which the effects of an artificial explosion have been traced.

Exhibition of Instruments. — To permit the examination by the public of apparatus which would not generally be readily accessible, several instruments not required for immediate use were sent to the exhibition of the Massachusetts Charitable Mechanics' Association. Gold medals were awarded to two of these instruments, the meridian photometer and the almucantar.

PUBLICATIONS.

The principal publications of the year were Volume XIV., Part II. of the Observatory Annals, and the Catalogue of 1213 Stars which will form a part of Volume XV. The second part of Volume XIV. contains a discussion of observations by ancient and modern observers to determine stellar magnitudes, with an explanation of the methods by which the final results of these observations as given in Part I. of the same volume were ascertained. It also investigates various sources of error likely to affect the determination of the brightness of stars, and compares the general result reached with the meridian photometer and those obtained by other means.

The Catalogue of 1213 Stars, prepared by Professor Rogers, contains the results of observations which he carried on with the meridian circle from 1870 to 1879. The catalogue contains accurate places of many stars which, although moderately bright, had previously been only imperfectly observed; and also furnishes means for the more precise determination of the places of numerous fundamental stars.

FORTY-FIRST

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE DECEMBER 7, 1886, AND
LAID BEFORE THE BOARD OF OVERSEERS, JANUARY 5, 1887.

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FORTY-FIRST

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE DECEMBER 7, 1886, AND
LAID BEFORE THE BOARD OF OVERSEERS, JANUARY 5, 1887.

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REPORT.

To the President of the University:

Sir, — The munificence of the late Robert Treat Paine has now begun to provide the encouragement which he desired to give to the science of astronomy. The sum of $164,198, comprising about half of his bequest, has been received by the Treasurer of the University, and the income of this fund is now available for the support of work at this Observatory. The previous funds available for that purpose amounted on September 1, 1875, to $164,067, and on September 1, 1885, to $226,988. On September 1, 1886, with the addition of the sum received from Mr. Paine's estate, they had risen to $398,046. This increase in the means of the Observatory will ultimately permit a corresponding extension of its work, but for the moment will largely be required for the publication of observations already made, and for effecting permanent improvements in the condition of the institution which have long been urgently needed. Some of these improvements have already been undertaken, but others will soon be necessary. Among these one of the most important is the remounting of the large telescope in a manner conformable to that provided for similar instruments at observatories more recently founded. The telescope also requires eye-pieces and other appliances of the kind now generally in use. The question of a new building must also soon be considered. The present building is one of the oldest belonging to the University beyond the limits of the College Yard. In many respects it is not adapted to the demands of modern astronomy, and will in any case need extensive repairs. The principal of the invested funds of the Observatory is not available for these improvements, and if they are to be paid for from the income, the work cannot be completed for a series of years and will materially interfere with the prosecution of any new researches. It is therefore to be hoped that special means may be obtained for meeting the want just mentioned.

Another method in which any new funds available for astronomical purposes might be advantageously employed at this Observatory has been pointed out in a recent pamphlet on the extension of astronomical research. This plan contemplates the support of researches conducted at other places by funds administered here. If the project should commend itself to those desirous of giving further encouragement to astronomy, it is confidently expected that the results would be very large as compared with the expenditure required to obtain them; for instruments and observers now idle might then efficiently contribute to the progress of science in various parts of this country or of the world. The breadth of this plan, since it contemplates aiding astronomy in general rather than this Observatory in particular, may, it is hoped, commend it to those who have not hitherto felt a special interest in Harvard University, but who may desire to aid astronomical science in the most effective way.

The fund of $10,000 established in 1871, the income of which has hitherto been employed in the payment of annuities, has recently become available. This fund will form an important addition to the means of the Observatory, especially as the use of its income is unrestricted. It is now called the Augustus Story Fund, and its amount on September 1, 1886, was $13,380.

The resignation of Professor William A. Rogers has deprived the Observatory of a valued assistant who has devoted many years to laborious astronomical work. Almost all of the observations in the extensive investigations conducted with the Meridian Circle, since its mounting in 1870, have been made by him and reduced under his direction. Fortunately an arrangement has been made by which he will still retain the superintendence of this work, and its publication will be completed as soon as possible. Three volumes of the Annals and a part of a fourth containing these observations have already been published; and three or four more will be required to complete their publication.

The most important extension of the work of the Observatory which has recently been made, was effected last spring by the liberality of Mrs. Henry Draper. As a memorial to the late Professor Henry Draper, the study of the photography of stellar spectra undertaken by him is now being carried on at this Observatory on a scale appropriate to the advance in this department of science. This work will be considered more in detail in the following description of the various investigations now in progress here.

EAST EQUATORIAL.

Eclipses of Jupiter's Satellites. — The photometric observation of these eclipses has been continued upon the system adopted in 1878. The total number of eclipses thus observed is now three hundred and fifty-eight, thirty-nine of which have occurred since the end of October, 1885.

Comparison Stars for Variables. — The observation of these stars with the wedge photometer has been continued through the year upon the plan described in the last report, and has formed the principal work of the instrument whenever its use for some special purpose was not required. All observers of variable stars are again requested to communicate to this Observatory the comparison stars which they have employed, so far as these are not already contained in the lists published by Argelander and others.

New Stars in Orion and Andromeda. — A cable message announcing the discovery of a new star near χ^1 *Orionis* was received in the afternoon of December 16, 1885. After transmitting this intelligence to other American astronomers, observations were at once commenced upon the new object and continued throughout the greater portion of the night. The position of the new star was determined with the equatorial and meridian circle; its brightness was measured with the wedge photometer and the meridian photometer, and was also estimated. Its spectrum was examined with the large equatorial. Two photographs of the star, and one of its spectrum, were also taken. The results of these observations made up to $1^h\ 30^m$ A.M. on December 17th were at once communicated to the press, and appeared in the newspapers of the same morning. On subsequent nights these observations were repeated, measures being made with the meridian circle on seven nights, with the meridian photometer on twenty nights, and with the wedge photometer on eight nights. Photographs were taken of the region containing this object on thirteen nights. The absence of the star from one of these showed that it must have been much fainter on November 9, 1885, than when it was discovered six weeks later. The spectrum was also photographed on five nights.

Observations of the region containing the temporary star in the nebula of Andromeda were continued until January 7, 1886. The total number of dates on which the region was observed was twenty-three.

Photographic Experiments.— The East Equatorial was frequently employed during the year in experiments upon photographing the spectra of stars. Usually a prism was placed before the object-glass of the instrument, but the effect was also tried of attaching a large spectroscope to the tail-piece.

Comets. — The occasional observation of comets by Mr. Wendell has continued, as in former years, to form part of the work done by the East Equatorial. Comet 1885 V. was observed on five nights; comet 1886 I. on seven nights; Barnard's comet, discovered December 3, 1885, on six nights; the three comets discovered by Brooks on April 27, April 30, and May 22, 1886, were respectively observed on four, two, and two nights; and those discovered by Finlay and by Barnard on September 26 and October 4, 1886, were each observed on two nights.

MERIDIAN CIRCLE.

Owing to circumstances explained at the beginning of this report, the reduction and publication of work already done with this instrument is at present more desirable than the prosecution of new series of observations. The work of reduction has been actively continued through the year and has resulted in the publication of Volume XV., Part I., and Volume XVI. of the Annals of the Observatory. The first of these publications contains the annual results for the fundamental stars observed during the years 1870 to 1879, inclusive, and the individual results for the years 1883 to 1886. It also includes the results from the separate observations of stars belonging to various special classes, and the catalogue of 1213 stars, separately published last year.

Volume XVI. contains a tabular statement of the instrumental constants and a journal of the observations, beginning with the mean results obtained in right ascension and declination from the separate wires and microscopes, and resulting in the place of the star for the beginning of the year of observation.

The second part of Volume XV. will contain the catalogue of the zone stars, and will be printed as part of the general catalogue of stars in the northern hemisphere undertaken by the Astronomische Gesellschaft. The completion of the manuscript has been delayed by the comparison undertaken between the results obtained here and those found in previous catalogues.

A volume corresponding to Volume XVI., but relating to the zone stars instead of to the fundamental stars, will be required to complete the publication of the zone observations. The observations for absolute right ascension and declination, made by Professor Rogers during the period 1879 to 1883, inclusive, will furnish material for a separate volume, which will complete the work of the meridian circle still requiring publication.

MERIDIAN PHOTOMETER.

During the year ending November 1, 1886, 209 series of measures have been made with this instrument by Mr. Wendell and myself. The total number of separate photometric comparisons is 59,800. The corresponding numbers in the two previous years are 27,500 and 50,000. The instrument continues to give entire satisfaction and leaves little to be desired as a means of measuring the brightness of stars of the ninth magnitude or brighter. It possesses various advantages over the small instrument of the same kind employed in the Harvard Photometry. This is shown in the average deviation of the one hundred circumpolar stars employed as standards. The value of this quantity, which was .16 of a magnitude with the older instrument, has been reduced to .12 with the present instrument. Fainter stars are measured with still greater accuracy, the average deviation of stars from the fifth to the ninth magnitude but little exceeding a tenth of a magnitude. The rapidity of the observations is such that 179 stars have been measured by a single observer in one evening, four settings being made on each star. The rate of forty stars an hour is frequently maintained during the entire evening, and when there is no difficulty in identifying the stars, the rate of a star a minute is often exceeded. This rapidity is attained by saving time at every point except in making the actual settings. It is understood that the observer is always to take as much time as he desires for this part of the work.

Various tests have been applied to detect the presence of systematic errors in this instrument, so far with negative results. A comparison of the ten brightest with the ten faintest of the standard stars served to show whether the value of one magnitude was the same for this instrument as for that previously used. All of the observations made during the past four years with the present instrument give the same results within less than an hundredth part as that derived from the similar observations with the original meridian photometer. Another possible source of error was investigated by using a red and a blue star as alternate standards of comparison for other objects. No appreciable difference was detected over a range of more than seven magnitudes in the observations of either of the observers.

A comparison of the seven hundred stars common to the observations of Wolff, of Pritchard, and the Harvard Photometry showed that our results differed on the average from Wolff, after allowance for systematic differences, by .140 of a magnitude; from Pritchard by .145; while Wolff and Pritchard differed from each other by .192. A comparison of the fifty-five stars proposed by Professor Pritchard as standards, and measured by him on several nights, showed that the average deviation from the Harvard Photometry was only .104.

Dr. E. Lindemann, of the Pulkowa Observatory, who is conducting an extensive series of observations in stellar photometry by means of the Zöllner photometer, has sent lists of stars observed by him, for the purpose of comparison. These stars have been observed with the meridian photometer. A comparison between the results obtained at Pulkowa and Cambridge shows that the average deviation of a measurement of the difference in brightness between two stars observed at both places does not exceed one tenth of a magnitude.

The principal work of the meridian photometer, the revision of the Durchmusterung magnitudes, is now approaching completion, nine tenths of the observations having already been made.

During the coming year similar observations will be made upon stars situated in the first twenty degrees of south declination. All stars which have been used as comparison stars for variables, if brighter than the ninth magnitude, are also being measured. Various pieces of miscellaneous work have been undertaken. Among these are measures of the brighter known and suspected variables, the stars observed by Rosén, and various stars employed by different astronomers as standards of reference.

STELLAR PHOTOGRAPHY.

Bache Investigation. — The investigation in stellar photography undertaken with the aid of the Bache Fund and described in the last report is now nearly completed. The principal results obtained include photographs of the entire sky north of —30° on which all stars bright enough to leave trails without the aid of clock-work are depicted. One series of plates exhibits the effect of atmospheric absorption on nearly every night of observation for a year. A large number of photographs of stellar spectra were also taken. Provision has been made for reducing most of the latter photographs, but the reduction of the others has not yet been undertaken. Among the miscellaneous observations may be mentioned some experiments in the application of photography to transit instruments, which showed that the accidental errors did not reach one half of those affecting eye-observations. Various photographs were taken of the nebula of Orion to show the relative brightness of different portions of this object. The nebulae in Andromeda, in Lyra, and in the Pleiades were also photographed. An attempt was made to photograph a satellite of Jupiter while undergoing eclipse, and thus determine the time of this phenomenon.

Henry Draper Memorial. — An investigation has been undertaken which promises to lead to an important extension of our knowledge of the stellar universe. As has been already stated, by the aid of Mrs. Henry Draper the study of the photographic spectra of the stars is being carried on with appliances which are probably unequaled elsewhere. Three researches are now in progress. The first includes a general survey of stellar spectra. Each spectrum is photographed with an exposure of not less than five minutes, and these photographs generally exhibit the spectra of all stars brighter than the sixth magnitude with sufficient distinctness for measurement. The greater portion of the sky north of —30° has been surveyed in this work, which will be repeated during the coming year. 151 plates have been measured and 5431 spectra examined and classified. Of these 4148 have been identified and the name and position of the corresponding star entered opposite each. The completed work will form a catalogue probably containing three or four thousand stars, each photographed on several plates.

The second research relates to a determination of the spectra of the fainter stars. Each photograph taken in the course of this research receives an exposure of one hour, so that the spectra of all the stars not fainter than the eighth or ninth magnitude, and included in a region ten degrees square, are represented upon the plate. On 58 plates 2416 spectra have been measured, and of these 2359 have been identified.

In both of these investigations the eight-inch Bache telescope has been employed. The third research relates to a more careful study of the spectra of the brightest stars. For this work Mrs. Draper has lent the 11-inch photographic lens employed by her husband. She has also furnished an admirable mounting for the instrument, and a small observatory to contain it. Two prisms have been constructed to place in front of the object-glass, the large one having a clear aperture of eleven inches square, and an angle of nearly 15°, the other being somewhat smaller. The preliminary results attained with this apparatus are highly promising. The account of them, however, will more properly belong to the report of the following year.

MISCELLANEOUS.

Variable Stars. — Messrs. Parkhurst, Eadie, Hagen, and Zaiser, have continued their observations in coöperation with this Observatory, as heretofore, and have still further increased the large amount of material collected by their industry for the study of the changes occurring in variable stars. Mr. Parkhurst has also made various interesting researches upon photometric questions, the results of which he has frequently appended to his records of observation. Mr. E. F. Sawyer, of Cambridgeport, has also reported the results of observations of variable stars made by him. Communications, which have been recorded in a report upon the subject published early in the year, were received from the following foreign observers of variable stars: Mr. T. W. Backhouse, of Sunderland, England; Dr. N. C. Dunér, of Lund, Sweden; Rev. T. E. Espin, of Wolsingham, England; Mr. J. E. Gore, of Ballysodare, Ireland; Dr. E. Hartwig, of Bamberg, Germany; Mr. George Knott, of Cuckfield, England; Professor Safarik, of Prague, Austria.

Estimated Magnitudes. — A valuable series of comparisons by estimation between stars of various magnitudes, made by M. P. Stroobant, of Brussels, was kindly furnished by the observer for reduction and publication at this Observatory. The copy of these comparisons sent by M. Stroobant was part of the mail carried by the steamship Oregon, and was supposed to have been lost by the sinking of that vessel. But after a submersion of about fifteen weeks it was recovered in an entirely legible condition by the skill of the American Wrecking Company, and forwarded to the Observatory.

Time Signals. — The increasing difficulties in transmitting these signals, and the efforts made to improve the service, were mentioned in the last report. The methods adopted have proved efficient,and the distribution of the signals throughout the year has gone on in a satisfactory manner. The Boston Time Ball, now mounted on the building of the United States Post Office, was dropped at noon on week days 295 times. On five other occasions, having failed to drop at noon, it was dropped five minutes later, according to the custom in such cases.

Telegraphic Announcements. — The telegraphic distribution of important astronomical discoveries or data has been continued during the year under the management of Mr. Ritchie, as before. Announcements have been made of the discovery of ten asteroids, nine comets, one meteoric shower, and one new star. There have been sent to the European union of astronomers, or received therefrom, twenty cable messages, and the number of telegrams sent in this country was 450, an increase of 190 as compared with the previous year.

The Associated Press has been regularly notified of the facts thus distributed and the information has been widely spread by means of the newspapers. Among other items of information may be noted the receipt of various positions of comets observed at the United States Naval Observatory, Washington. These positions were published as soon as possible after their receipt and have proved useful in the computation of orbits.

Buildings and Grounds. — Various important repairs in the main building of the Observatory will soon become necessary, unless means can be secured for replacing it by a new structure. The entire exterior, and most of the interior of the building, requires painting; new floors are needed, and additional space will become imperative. Besides the usual care of the grounds, a number of rare trees and shrubs have been planted which in a few years will greatly improve the appearance of the place. The most important improvement is the construction of a substantial fence on the north side of the grounds, which was needed to protect the numerous valuable instruments now located in small buildings near the Observatory. A drain has also been laid on the southern and eastern sides of the main building.

PUBLICATIONS.

The principal publications of the year were Volume XV., Part I., and Volume XVI. of the Observatory Annals, which have been described above. Two treatises in quarto form, on the apparent position of the zodiacal light, and on stellar photography, have also appeared in the Memoirs of the American Academy of Arts and Sciences, as is shown in the list which follows.

These publications have appeared either as official communications from the Observatory or as papers prepared by its officers individually.

Fortieth Annual Report of the Astronomical Observatory of Harvard College.

A Plan for the Extension of Astronomical Research. By Edward C. Pickering. Cambridge, 1886.

Faint Stars for Standards of Stellar Magnitudes. By Edward C. Pickering. Sidereal Messenger, iv. 24; Astronomical Register, xxiii. 39.

Photographic Study of Stellar Spectra. Henry Draper Memorial. By Edward C. Pickering. Circular, reprinted in Nature, xxxiii. 535, and Science, vii. 278.

Accurate Mountain Heights. By Edward C. Pickering. Appalachia, iv. 215; Science, vii. 423.

Comparison of Maps of the Ultra Violet Spectrum. By Edward C. Pickering. American Journal of Science, cxxxii. 223.

Draper Memorial Photographs of Stellar Spectra exhibiting Bright Lines. By Edward C. Pickering. Nature, xxxiv. 439.

Comet 1883 I. (Brooks). By O. C. Wendell. Sidereal Messenger, v. 92.

On the New Nebula discovered in the Pleiades by MM. Henry. By Edward C. Pickering. Astronomische Nachrichten, cxiii. 399.

Photometric Observations of the New Star near χ^1 *Orionis*. By Edward C. Pickering. Id. cxiv. 283.

Orbits of Meteors. By O. C. Wendell. Id. cxiv. 285; Sidereal Messenger, v. 111.

Comet-Meteor Radiants. By O. C. Wendell. Astronomische Nachrichten, cxiv. 329; Sidereal Messenger, v. 152.

Magnitudes of Comparison Stars employed in Dr. Müller's determination of the Phases of Asteroids. By Edward C. Pickering. Astronomische Nachrichten, cxiv. 413.

Orbit of Comet 1886 (Brooks 2). By O. C. Wendell. Id. cxiv. 415; Sidereal Messenger, v. 220.

Positions of the New Star near χ^1 *Orionis*. By Edward C. Pickering. Astronomische Nachrichten, cxv. 31.

Early Experiments in Telegraphing Sound. By Edward C. Pickering. Proc. Am. Acad. of Arts and Sciences, xxi. 262.

Atmospheric Refraction. By Edward C. Pickering. Id. xxi. 268.

A New Form of Polarimeter. By Edward C. Pickering. Id. xxi. 294.

Observations of Variable Stars in 1885. By Edward C. Pickering. Id. xxi. 319.

The Apparent Position of the Zodiacal Light. By Arthur Searle. Memoirs of the Am. Acad. of Arts and Sciences, xi. 135.

An Investigation in Stellar Photography. By Edward C. Pickering. Id. xi. 179.

The Longitude of the McGill College Observatory. By Professor W. A. Rogers, Harvard College Observatory, and Professor C. H. McLeod, McGill College Observatory. Trans. Roy. Soc. Canada, Section iii., 1885, page 111.

EDWARD C. PICKERING, *Director.*

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REPORT.

To the President of the University:

Sir, — The work of the Observatory has been largely increased during the past year by means of three important accessions to its resources. The plans for the study of stellar spectra conducted as a memorial to the late Dr. Henry Draper have been greatly enlarged by Mrs. Draper's continued liberality. The fund left by the late Uriah A. Boyden for the establishment of a mountain observatory has been transferred by its Trustees to the President and Fellows of Harvard College, and the researches undertaken by its means are now directed at this Observatory. Finally, the income of the large bequest of the late Robert Treat Paine has been available for the support of Observatory work during the entire year. Each of the sources of income above enumerated is greater than that often provided for the entire maintenance of an independent observatory, and, in comparison with what is ordinarily attainable, this institution can no longer be regarded as inadequately endowed. It would be a serious mistake, however, to infer from this circumstance that the want of additional funds with which important and, from the scientific point of view, urgently required researches may be supported has ceased to be felt. All endowments require increase as time passes, since the rate of income from invested property continually tends to diminish in countries where wealth is increasing. But apart from this consideration, the new resources of the Observatory are already so much absorbed in the work which has been undertaken with their aid that it is extremely difficult to spare any part of them for the improvement of the building or for the publication of the results obtained by observation. Yet, as has been remarked on former occasions, attention to these wants of the Observatory can hardly be delayed. It is probable that there has never been a time in the history of the institution when so large a return could be obtained for a given additional expenditure of money as would now result from the command of means sufficient for the desired improvements. The principal building, as was stated in the last report, is inadequate to the requirements of modern astronomy and to the present needs of the Observatory. A temporary remedy for the want of space which is now seriously felt would be to occupy the east wing of the building, now used as the residence of the Director, for scientific purposes. In this case it would be necessary to build a new dwelling-house near the Observatory. This addition is also desirable on the ground that the east wing of the Observatory is ill adapted for use as a dwelling.

In order to prevent an undue increase in the length of these reports, it will be necessary to describe the progress of the work of the Observatory more concisely than heretofore. It will be given under three principal headings, the Observatory Instruments, the Draper Memorial, and the Boyden Fund.

The Observatory is indebted to Professor William A. Rogers for the contribution of a portion of the expense of constructing a comparator made under his supervision, and also for a careful study of the errors of a thermometer belonging to the Observatory.

OBSERVATORY INSTRUMENTS.

East Equatorial. — This instrument remains in good condition, but still in great want of facilities for its more convenient use, such as are now commonly provided for telescopes of its class. Its principal work has been the continuation of the observations on eclipses of Jupiter's satellites and on the comparison stars for variables. The weather proved unusually unfavorable to the first of these researches. Out of 68 eclipses which might have been observed if the weather had permitted, only 16 could be observed fairly well; 7 more were observed imperfectly through clouds, so that the total number is 23 for the year, and 381 in all. The observations of comparison stars for variables were nearly complete, so far as regards the list of such objects originally compiled, when the series was terminated by the accidental breaking of the wedge. The wedge photometer now employed in the continuation of the work and in other investigations is that mentioned in the Fortieth Report as made in England for this Observatory under the superintendence of Professor Pritchard; but the details of the apparatus have been somewhat modified since the instrument was received. It was investigated by Professors Langley and Young, as will be mentioned in describing the publications of the year, and after its return to this place the wedge was removed from the remainder of the apparatus and mounted in the focal plane of the telescope in a manner proposed by Professor Searle. The star to be observed is viewed between two bars placed at right angles to the wedge and rigidly connected to the index of the scale, but movable in the field for convenience of adjustment. In this form the instrument gains in facility of use, and the inaccuracy to be apprehended from a larger field of view and the occasional presence of other stars, or general brightness of the sky, does not seem to be important. It is probably counterbalanced by the additional security that the entire beam of light from the eyepiece is properly received by the eye when the field is visible. From observations made on 25 nights the average deviation of one observation from the mean of a set of six, expressed in magnitudes, is 0.19; if one night is excluded, on which the observations were thought to be affected by variable haze, the result is 0.15. The average deviation of the result for a single star upon one night from the mean of three nights is 0.09. It is proposed to employ the instrument in the observation of zones of DM. stars, and in the investigation of the phases of asteroids.

Occasional observations of comets have been made by Mr. Wendell as in former years. Comet 1886 VII. was observed on one night; Comet 1886 VIII. on one night; Comet 1886 IX. on one night; Comet 1887 II. on two nights; Comet 1887 III. on four nights; Comet 1887 IV. on thirteen nights. The comet recently discovered by Brooks (a return of Olbers' Comet) has been observed on four nights. At the request of Mr. R. Bryant the asteroid (80) Sappho was observed by Professor Searle on seven nights.

Meridian Circle. — The only observations made with this instrument at present are those needed for the determination of clock error, since the accumulation of unpublished results obtained with it still demands the use of the resources applicable to this department of work. But at the request of Dr. Auwers this Observatory has agreed to undertake the observation of one of the zones required in the proposed revision of the Southern Durchmusterung. These observations will be begun with the meridian circle as soon as possible after the definite assignment of the zones to be revised, which has not yet been made by the Astronomische Gesellschaft.

The reduction of the observations still unpublished has been actively continued throughout the year, under the superintendence of Professor William A. Rogers, according to the arrangement mentioned in the last report. The preparation of the catalogue of zone stars between the declinations + 50° and + 55° is approaching completion. The results of the observations of these stars, including those observed in the revision made in 1883–85, have been reduced to the epoch 1875.0. The preliminary computation of the precession and secular variation has been completed, with the aid of tables previously prepared for the purpose. From twenty-eight published catalogues, 13,469 observations of stars in the zone have been brought forward to 1875.0, and the work of comparing these places with the zone observations is far advanced.

Meridian Photometer. — The work of observing the zones at intervals of five degrees undertaken with this instrument in the region covered by the Southern Durchmusterung is about half completed and will probably be finished within a year. The similar observations in the northern hemisphere are now substantially completed. Additional observations of groups of stars, also observed by Dr. Lindemann of the Pulkowa Observatory, have likewise been made, and many stars have been observed at the request of Mr. H. M. Parkhurst, to enable him to connect his photometric observations with the system of magnitudes here adopted. Similar observations would be gladly undertaken to assist the work of other astronomers who may desire them. The observations of the year have been made, as before, by Mr. Wendell and myself. They consist of 156 series, containing in all 47,476 settings. The average deviation, expressed in terms of stellar magnitude, for stars observed at the upper culmination, is 0.117.

Eclipse Observations. — The policy of the Observatory is generally to undertake large pieces of routine work in which some valuable result is certain to be attained rather than to make considerable expenditure for eclipses or other accidental phenomena in which failure could result from clouds.

The total eclipse of the sun on August 19, 1887, gave an unusual opportunity to study the solar corona at two points widely separated and thus indicate its fixity or motion during an interval of two hours. A plan was accordingly prepared by Mr. W. H. Pickering to test this question. By the courtesy of Professor C. A. Young, photographic apparatus was sent to Russia under his charge, and Professor Newcomb kindly authorized Professor Todd to have similar observations made in Japan. The plates were prepared here, tested by the exposure of a small part of each to a standard light, and were to have been developed and discussed by Mr. W. H. Pickering. Unfortunately, clouds prevented a successful result. The total cost to this Observatory did not exceed three hundred dollars. Had the weather permitted, photographs would have been obtained at each station with apertures of ten inches, giving images of the sun nearly an inch in diameter. In Japan photographs would also have been obtained on plates seventeen inches square, in which the sun would have a diameter of five inches without enlargement.

HENRY DRAPER MEMORIAL.

The progress of this work was detailed last spring in a report widely circulated and copied in various scientific journals. Of the various researches undertaken, the photographs of the spectra of the brighter stars north of — 25° are now completed. Each portion of the heavens should appear on at least four plates, of which 633 in all have been made. Each plate covers a region 10° square, from two to five exposures of five minutes each being made on every plate. The total number of spectra contained in this work is 27,803. The greater portion of these have been measured, the character of the spectra indicated, and the corresponding stars identified. The places of these stars for 1900 have also been computed and the preparation of a catalogue will shortly be undertaken.

A beginning has also been made in the study of the photographic brightness of these spectra. As the effect of color is thus eliminated, this method, if successful, may supersede all photometric determinations and eye estimates of stellar magnitude. A second research will give to each plate an exposure of an hour, and thus include fainter stars. The entire sky north of — 20° would be covered twice by 655 plates, if no defective plates were taken. 192 plates have so far been measured, containing 9880 spectra, of which 9065 have already been identified. These photographs will be completed in one or certainly in two years from the present time. It is then proposed to send the instrument to the southern hemisphere and thus complete the work to the south pole. A third research is carried on with the 11-inch refractor formerly owned by Dr. Henry Draper. This instrument has been mounted in a wooden building surmounted by a dome of twenty feet in diameter. Four prisms, each nearly a foot square, cover the object-glass and give spectra about five inches long. All of the stars brighter than the third magnitude have been photographed with this apparatus. These photographs are then enlarged by the aid of a cylindrical lens so as to form images several inches in length, and of any desired width. Several hundred lines are visible in many of these spectra. For a more detailed study of the spectra of the fainter stars Mrs. Draper has sent to Cambridge the 15 and 28 inch reflectors constructed by Dr. Draper. They are to be mounted in a building recently erected to contain them. They will be employed in studying the spectra of the variable stars, of the banded stars, and of those stars in which the first investigation mentioned above indicates any peculiarity of spectrum. Besides an observer and corps of computers for this work, Mrs. Draper has furnished a second observer, who maintains the work during the latter part of the night until interrupted by daylight. The total number of photographs so far taken with the 8-inch telescope is 1792, with the 11-inch 732. The photographs are developed in a cottage recently rented by the Observatory and especially fitted up for photographic work. Various novelties are contained in it; for instance, an arrangement for exposing the plates automatically to a standard of light for exactly one second, the enlarging apparatus, and other appliances constructed especially for this work.

BOYDEN FUND.

A fund, now amounting to about $238,000, was left by the late Uriah A. Boyden for conducting astronomical observations at such a height as to be free, so far as possible, from the injurious effects due to the atmosphere. Last spring the trustees of the fund concluded to transfer it to the President and Fellows of Harvard College. Mr. W. H. Pickering was appointed as assistant in charge of this work and since then has devoted his time to devising, constructing, and testing the new class of instruments required. An object-glass of twelve inches aperture was purchased and mounted on a wooden support, so that it could be directed to the pole-star. Two images of this object were formed by a double-image prism and their diameters measured under various atmospheric conditions. Photographs of the trail of the spectrum of the brighter stars also served to measure the steadiness of the air in various localities. The clearness of the air was determined by similar observations near the horizon, and also by photographing the trail of stars near the north pole of the heavens and near the horizon upon the same plate. Another test of the clearness of the sky is found by photographing upon the same plate the sky near the sun, and at a distance from it, and also exposing the plate to a light of constant intensity.

A study of the transparency of the air to the violet rays was made with a spectroscope whose lenses and prisms were made of quartz. The meteorological conditions of the atmosphere are examined by self-recording instruments. Besides the usual forms of thermograph and barograph a form of sunshine recorder has been devised which indicates on a single sheet all the morning hours during a month in which the sun is shining. An instrument has also been constructed for recording the hours during which the sky is clear at night. A photograph of the trail of the pole-star is taken every evening by a small telescope, which is closed automatically every morning before twilight begins.

All of these instruments, except the pole-star recorder, were tried by Mr. Pickering, two assistants, and myself in the clear air of Colorado. They were mounted and carefully tested at an altitude of 14,000 ft. on Pike's Peak, at 11,000 ft. at Seven Lakes, and at 6,000 ft. at Colorado Springs. A comparison with the results at Cambridge near the sea level exhibits the effect of varying the altitude of the place of observation to the extent of nearly three miles.

Visits were also made to Mt. Lincoln, 14,300 ft., Mt. Bross, 14,000, and various points reached by railroad at heights exceeding 11,000 ft., to determine the availability of these points for a permanent station.

Important aid was rendered in the study of the climate of Colorado by Professor F. H. Loud, who was enabled to aid officially in this work by the courtesy of the trustees of Colorado College. With his assistance stations have been established upon Mt. Lincoln, Mt. Bross, and at various lower points. By the coöperation of the U. S. Signal Service self-registering instruments are now in operation at Pike's Peak, Colorado Springs, and Denver. A large number of vertical and horizontal angles were obtained by means of a micrometer level, showing the positions of the mountains seen from various points in Colorado. It is expected that important additions will thus be made to our knowledge of their heights and locations. Photographs of the solar spectrum in Colorado permit prints to be made extending to the wave-length 292 and showing many lines not contained in any work hitherto published.

A telescope of thirteen inches aperture and fifteen feet focus, so constructed that it can be used for either visual or photographic purposes, is now nearly completed by the firm of Alvan Clark & Sons. A second telescope of eight inches aperture, eleven feet focus, will be mounted upon the same stand. This last lens is a doublet, and is intended to make charts of the stars 5° square, on the same scale as the charts of Peters and Chacornac.

A dome is now nearly completed on the Observatory grounds in which these instruments will be mounted and thoroughly tested. A second building, forty feet long, is also being erected for spectroscopic and photographic purposes. A large collection of books, maps, and photographs relating to mountains in all parts of the world has been made, and an extensive correspondence on the same subject has also been opened. Next summer a second expedition will be made to Colorado, and it is hoped that observations may be maintained there permanently in connection with this Observatory. Later it is purposed to test some insular climate like that of the Sandwich Islands, and plans are already proposed for observations in Peru, where two railroads reach the heights of 15,800 and 14,600 ft. respectively.

MISCELLANEOUS.

Variable Stars. — Messrs. Parkhurst, Eadie, Hagen, and Zaiser have continued their coöperation with this Observatory in collecting fresh material for the study of the variable stars. An interesting research undertaken during the year by Mr. Parkhurst relates to the variations of asteroids due to distance and phase, and possibly also to rotation or other causes as yet undetermined. It is expected that a preliminary series of these observations will soon appear as one of the sections of the eighteenth volume of Annals. Communications, which have been recorded in a report upon the subject published during the summer, were received from the following foreign observers of variable stars: Mr. T. W. Backhouse, of Sunderland, England; Messrs. Joseph Baxendell and Joseph Baxendell, Jr., of Southport, England; Dr. N. C. Dunér, of Lund, Sweden; Rev. T. E. Espin, of Wolsingham, England; Mr. J. E. Gore, of Ballysodare, Ireland; Mr. George Knott, of Cuckfield, England; Professor Safarik, of Prague, Austria; Mr. T. S. H. Shearmen, of Brantford, Canada. It is proposed that the corresponding report, to be published during the coming year, shall contain an index to all observations of variable stars, so far as their existence may be known, whether published or not. All who can furnish information tending to make this report more complete, especially with regard to the unpublished observations, are requested to communicate it to this Observatory.

Time Service. — Two important improvements have been made during the year in this department of the work of the Observatory. A new mean time clock, Ballou No. 103, has been tested and delivered to the Observatory according to contract. It has been used as the origin of the signals since June, 1886. The average amount of its error at the times of observing star transits has been $0^s.30$, the average interval between the times of these determinations being 2.1 days. The average error of the clock at 10 A.M. has been $0^s.26$, while the average change in the daily rate from each day to the next has been $0^s.19$. The clock can obviously be so managed as to diminish either of the amounts last named, if the other is allowed to increase. A more rapid compensation of the error, however, would be inconvenient to the watchmakers who use the signals. As the Observatory now possesses two mean time clocks, it will be practicable to make use of one of them as a standard time-piece, while the other is employed as the origin of the signals. Moreover, when either of the clocks requires repairs, the signals can be continued by the other. The second improvement above mentioned consists in the considerable additions made to the line of wire conveying the signals. The work has been planned so that it will tend to the ultimate establishment of two Observatory lines of wire to Boston, with sections interchangeable between switch boards accessible by telephone.

Telegraphic Announcements. — The telegraphic distribution of astronomical intelligence has been continued during the year under the management of Mr. Ritchie. Announcements have been made of the discovery of seven asteroids and six comets. There have been sent to the European union of astronomers or received therefrom fifteen cable messages, and the number of telegrams sent in this country has been 325.

Buildings and Grounds. — The need of a new building has been pointed out in the beginning of this report, and as additional space for computation and the preservation of records will continue to be required, it is expected that the inadequacy of the present building will constantly become more apparent. A temporary remedy has been sought in securing the use of two small houses on Madison Street. One of these belongs to the College and has been hired by the Observatory. It serves as a photographic laboratory and for other purposes, generally connected with the work of the Draper Memorial. The other house has been purchased, and will chiefly be serviceable in connection with the work of the Boyden Fund. In supplying the want of additional room for new instruments, it has appeared best to follow the modern practice of providing each with its own building. Two buildings surmounted by domes about twenty feet in diameter have been erected to accommodate the 11-inch refractor and the 28-inch reflector of Dr. Draper, and a similar building is in course of construction for the instrument to be employed in experimental work under the Boyden Fund.

Publications. — Volume XVII. of the Annals of the Observatory has been published during the year. It contains Mr. Chandler's treatise on the Almucantar, which explains the theory of this instrument and exhibits the results of the observations made with it by the author. Volume XVIII. will consist of comparatively short separate articles, which will be successively distributed as soon as published, in order to place them earlier in the hands of astronomers. Two numbers of the series have already appeared. The first, entitled "Magnitudes of Stars employed in various Nautical Almanacs," contains a list of the stars for which ephemerides are given in the almanacs published by government authority in the United States, England, France, Germany, and Spain, with the magnitude of each star as determined by the Harvard Photometry, the Uranometria Oxoniensis, Wolff's photometric observations, and the Uranometria Argentina. The almanacs of the United States, France, and Spain intend to employ these magnitudes hereafter, and the American Ephemeris for 1890, in which this change has been made, has already appeared. The second number of Volume XVIII. contains a discussion of the Uranometria Oxoniensis.

A treatise in quarto form, by Professors S. P. Langley, C. A. Young, and E. C. Pickering, was published in the Memoirs of the American Academy of Arts and Sciences. It describes observations undertaken to test the applicability to photometric uses of the wedge of tinted glass made for this Observatory in England, and already mentioned in describing the work of the East Equatorial.

The following list contains the titles of other publications which have appeared during the year, either as official communications from the Observatory or as papers prepared by its officers individually: —

Forty-first Annual Report of the Astronomical Observatory of Harvard College.

Photographs of Stellar Spectra. By Edward C. Pickering. Nature, xxxiv. 570.

New Form of Construction of Object-glasses intended for Stellar Photography. By Edward C. Pickering. Ibid. xxxvi. 562.

Recommendations with respect to the proposed Photographic Chart of the Sky. By Edward C. Pickering. Letter, translated into French and published at page 93 of the work entitled "Congrès Astrophotographique International tenu à l'Observatoire de Paris pour le Levé de la Carte du Ciel," Paris, 1887.

Observations of Variable Stars in 1886. By Edward C. Pickering. Proc. Am. Acad. of Arts and Sciences, xxii. 380.

Boyden Fund. Circular, describing the objects of this fund. By Edward C. Pickering.

Boyden Fund. Circular No. 2. Meteorological Observations. By Edward C. Pickering.

Henry Draper Memorial. First Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory. Edward C. Pickering, Director. With Plate. Cambridge, 1887. Reprinted in Nature, xxxvi. 31, and Memorie della Società degli Spettroscopisti Italiani, xvi. 93.

Heights of the White Mountains. By Edward C. Pickering. Appalachia, iv. 305.

Observations of Comets (1886 VIII. and 1887 II.). By O. C. Wendell. Astronomische Nachrichten, cxvi. 191.

Observations of Comet 1887 III. By O. C. Wendell. Ibid. cxvi. 267. Also, Astronomical Journal, vii. 79.

Orbit of Comet 1887 III. By O. C. Wendell. Astronomische Nachrichten, cxvi. 317. Also, Sidereal Messenger, vi. 161.

The Luminous Bands Visible in and near the Zodiac. By Arthur Searle. Astronomische Nachrichten, cxvi. 323.

Observations of (80) Sappho. Communicated by Edward C. Pickering. Ibid. cxvi. 373.

Orbit of Comet 1886 IX. By O. C. Wendell. Ibid. cxvii. 59.

Orbit of Comet 1887 IV. By O. C. Wendell. Ibid. cxvii. 119.

Magnitudes of Circumpolar Stars determined at the Observatories of Moscow and of Harvard College. By Edward C. Pickering. Ibid. cxvii. 139.

Proposed Index to Observations of Variable Stars. By Edward C. Pickering. Ibid. cxvii. 167. Also, Monthly Notices of the R. Astr. Society, xlvii. 443, and Observatory, x. 301.

Observations of Comet 1887 IV. By O. C. Wendell. Astronomische Nachrichten, cxvii. 243. Also, Astronomical Journal, vii. 111 and 119.

EDWARD C. PICKERING, *Director*.

FORTY-THIRD

ANNUAL REPORT

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HARVARD COLLEGE.

BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE DECEMBER 15, 1888.

CAMBRIDGE, MASS.
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REPORT.

To the President of the University:

Sir, — The income of the Observatory has been greatly increased during the last two or three years. The amount is such that astronomical science should be materially advanced by its proper expenditure. To secure this end so far as possible the field of work of the Observatory has been widened, as will be seen in the following report. The coöperation of other institutions and individuals has been secured, especially in the department of meteorology, in such a way as to obtain results which would be impossible for a purely local institution. Daily experience in the industrial arts shows that large sums of money can be expended much more economically than small. It is hoped that the work now in progress will show that the same principle is applicable to a scientific institution. If this is true, a brilliant future may be expected for this Observatory from its many friends interested in advanced scientific work.

As will be seen below, Mrs. Draper's continued liberality permits the Henry Draper Memorial to progress rapidly, and the first large research in this department is now approaching completion. The Boyden Fund has given us more definite plans for a mountain observatory, while the Paine Fund, nearly unrestricted in its conditions, aids every portion of the work of the Observatory. Meteorological observations, hitherto somewhat restricted, will now be greatly extended by the liberal coöperation of Mr. A. Lawrence Rotch, of the New England Meteorological Society, and of other observers. This increase of work renders the need of a new building, pointed out in previous reports, still more urgent; but for this purpose the funds mentioned above are not available. Not only is the present space entirely inadequate for the large corps of assistants now employed, but what is more important, protection from fire is urgently needed. The instruments of an observatory are delicate, costly, and easily destroyed by fire. But the expense of replacing the manuscript of the observations made with them would be far greater, and would not be covered by the insurance. The value of the observations, according to this test, would often be five or ten times that of the instruments with which they were made.

OBSERVATORY INSTRUMENTS.

East Equatorial. — No alteration has been made during the year in the condition or appliances of this instrument. The observations for which it has been employed are as follows: The number of eclipses of Jupiter's satellites photometrically observed is 27, making in all 408; the comparison stars of 17 variables, each set usually upon two or three dates, have been observed with the modified wedge photometer described in the last report; the same photometer has been used in the observation of six asteroids, (3) Juno on 39 dates, (4) Vesta on 10, (7) Iris on 10, (8) Flora on 9, (11) Parthenope on 4, (82) Alcmene on 16; and zones of DM. stars have also been observed with the wedge photometer on 16 dates. Mr. Wendell has observed the positions of the following comets: 1887 V. on 2 dates, and the comets discovered by Sawerthal, Brooks, and Barnard, on 6, 8, and 3 dates respectively; also the asteroid (80) Sappho on 8 dates. In order to facilitate the decision of questions relating to the identity of stars observed with the meridian circle in the zone from + 50° to + 55°, 148 observations of 116 stars have been made with the Equatorial.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The catalogue of the zone from 50° to 55° of north declination is completed as far as $12^{h.}$, and the copy is now in course of preparation for printing. The revision of the remaining portion of the catalogue is so far advanced that no delay will occur in the preparation of additional copy. The reduction to the epoch 1875.0 of the places of stars belonging to the catalogue, which occur in other authorities, has been completed and tables for the reduction of different catalogues to the fundamental system have been constructed. The corrections required on account of proper motion are now in course of investigation. For the observations made in the years 1879 to 1883 on the absolute places of stars, the means of the times of transit and of the circle readings have been computed and entered in the proper books.

The zone from — 9° 50′ to — 14° 10′ was assigned to this Observatory as its part in the revision of the Southern Durchmusterung mentioned in the last report. The number of stars to be observed in this zone is 7959. Observations were begun on April 26, 1888, and at the close of October had been made on 56 evenings. The total number of observations was 2106, some of which, however, will probably be unavailable, owing to the failure of the chronograph or other imperfections in the record. Of these observations, 105 relate to circumpolar stars, 354 to fundamental stars, 1549 to zone stars, and 42 to stars incidentally observed, more particularly to a series of comparison stars for the asteroid Sappho, observed at the request of Mr. R. Bryant of London. The telescopic observations have been made by Professor Searle; the microscopes were read by Mr. T. F. White until the end of September, and since then by Mr. J. A. Dunn. The chronograph sheets have been read by Mr. Dunn, who has made some progress in the further reduction of the work.

Meridian Photometer. — The work planned for this instrument began early in 1882 and was completed September 29, 1888. The total number of series of observations was 1067, including 266,912 photometric comparisons. Of these, 163 series and 58,256 comparisons were made since November 1, 1887. The principal investigation made with this instrument was the determination of the brightness of stars of the ninth magnitude in zones 20′ in width at intervals of 5° from the north pole to the declination — 20°. Stars from the sixth to the eighth magnitude in wider zones were also included. Among other objects measured were the 722 stars adopted as standards of magnitude for the Uranometria Argentina; those observed by Flamsteed and not included in the Harvard Photometry; those of the latter catalogue which were discordant, and stars of the ninth magnitude and brighter used as comparison stars for variables. Numerous variables, suspected variables, planetary nebulae, stars having peculiar spectra, asteroids, etc., were also included in this work. Stars near the northern and southern horizon have been observed with the object of determining the law of atmospheric absorption to within two degrees of the horizon. The instrument will now be sent to Peru, where the Harvard Photometry will be extended to the south pole. A similar investigation will also be made of fainter stars to the ninth magnitude in zones at intervals of 5° from — 25° to — 90°.

Horizontal Telescope.—All stars of the sixth magnitude and brighter visible in Cambridge were measured with the first meridian photometer in 1879 to 1882. Nearly one hundred thousand comparisons were made and their results, published in the Harvard Photometry, established a photometric scale for the bright stars. This scale has been extended from the sixth to the ninth magnitude by the meridian photometer mentioned above. It is now proposed to continue this scale from the ninth to the fourteenth magnitude by a third still larger instrument of somewhat similar form. A telescope having an aperture of twelve inches and a focal length of seventeen feet has been mounted horizontally pointing to the west. A mirror placed in front made in accordance with which the long series of meteorological observations made at the summit of Pike's Peak has been furnished for publication in the Annals of the Observatory. This work is now far advanced. The continuance of the observations to the summer of 1888 was also assured by assistance from the Boyden Fund.

The meteorological station on Mt. Lincoln, mentioned in the last report, was discontinued after some months, but that on Mt. Bross has been continued; and assistance has been given, with the aid of the kind intervention of Professor Loud, to other meteorological work in Colorado, especially by means of self-registering instruments. Assistance has also been given in the publication of the Bulletin of the Colorado Metereological Society.

Arrangements have been made for beginning meteorological work at several places in Peru. This work is under the general supervision of Mr. V. H. MacCord, to whom the Observatory is much indebted for his kind assistance. Mr. W. H. Cilley, of the Oroya Railroad, has also kindly interested himself in furnishing highly valuable information and in securing observations.

The investigation of the clearness and steadiness of the air at Cambridge has been continued by the photographic methods mentioned in the last report; these are as follows: photographs of the trails of the spectra of bright stars, photographs of the trails of stars near the North Pole and near the horizon, and photographs of the sky at different distances from the sun. The 13-inch and 8-inch telescopes mentioned in the last report were mounted early in the year, and the first of these instruments has been kept in nearly constant use since then. Eleven hundred photographs have been taken of a variety of objects to show what results may be expected under the atmospheric conditions existing at Cambridge.

Photographs have been taken of 112 double stars whose components are two seconds or more apart and either of them as bright as the seventh magnitude. The relative brightness of the components will be determined as well as their positions. The stars have also been allowed to trail over the plate, and this gives an excellent test of the steadiness of the air. Among other investigations made with this instrument are the determination of the actinic albedos of the Moon and planets and the absorption towards the limb of the planet Jupiter. Photographs were obtained of the outer satellite of Mars, and of all the satellites of Saturn and Uranus except Mimas. It was shown that no undiscovered satellite of Saturn existed revolving in an orbit between Enceladus and Iapetus, unless it was more than a magnitude fainter than Hyperion. Probably no such satellite exists outside of Iapetus. Charts were constructed of the region near the

North Pole, of the Pleiades, and of some other clusters and nebulae. A study was also made of various lenses for enlargements and of various camera lenses. Sundry other photographic investigations have also been carried on. The total number of photographs taken in this department of the Observatory during the year is about thirty-five hundred.

MISCELLANEOUS.

Meteorology. — For many years after its establishment, meteorological observations formed an important part of the work of this Observatory. Its statutes define one of its objects to be coöperation in meteorological investigations. In recent years the United States Signal Service has so fully provided for this work that less attention has been paid to it here. By the coöperation of the New England Meteorological Society, the observations of the one hundred and fifty members of that society will hereafter be published in the Annals of this Observatory. We shall thus be enabled to exhibit the climatic conditions of a large part of New England. An active meteorological observatory, fully equipped with the best self-recording instruments, has recently been established on Blue Hill. The location is exceptionally favorable, as it is the highest point of land in eastern Massachusetts and the highest point near the sea from Maine to Florida. By the liberal aid of the owner, Mr. A. Lawrence Rotch, these observations will hereafter appear in our Annals, and the eventual consolidation of the two institutions is contemplated. It therefore appears to be advisable to restrict the meteorological observations at Cambridge to such as will make the early observations a part of a continuous series. Other important observations are being made with the aid of the Boyden Fund, as has been stated above.

Variable Stars. — Messrs. Parkhurst, Eadie, and Hagen have continued their coöperation with this Observatory in collecting fresh material for the study of the variable stars. Mr. Parkhurst's preliminary series of observations on the variations of the asteroids, mentioned last year, has been published as No. III. in the collection of separate memoirs which will constitute Volume XVIII. of the Annals of the Observatory. Communications which will aid in the construction of the Index to Observations of Variable Stars, undertaken last year, have been received from the following foreign observers: Mr. T. W. Backhouse, of Sunderland, England; Messrs. Joseph Baxendell and Joseph Baxendell, Jr., of Southport, England; Rev. T. E. Espin, of Wolsingham, England; Mr. J. E. Gore, of Ballysodare, Ireland; Mr. George Knott, of Cuckfield, England; Major E. E. Markwick, of Queenstown, Ireland; Mr. C. E. Peek, of Lyme Regis, England; Mr. J. Plassman, of Warendorf, Germany; Professor Safarik, of Prague, Austria. Two large series of earlier unpublished observations have also been obtained, and it has been thought best to delay the publication of the Index above mentioned until these series could be received and utilized. The first series consists of observations by the late Professor E. Heis, of Münster, Germany. The records of these observations were transmitted by the family of Professor Heis to the Rev. J. G. Hagen, S. J., who has kindly communicated them to this Observatory. The second series contains the observations of the late Dr. J. F. J. Schmidt, preserved in manuscript at Potsdam. Professor H. C. Vogel, Director of the Potsdam Observatory, has kindly directed the preparation of a copy of these observations for use in the proposed Index. The printing of the Index has been begun, and it is hoped that the work may soon be distributed.

Time Service. — The standard time signals have continued to be sent by the Ballou clock No. 103. The average amount of its error at the time of observing star transits has been 0.32 seconds; the average interval between the times of these determinations being 2.4 days. The average error of the clock at 10 A.M. has been 0.33 seconds, while the average change in the daily rate from each day to the next has been 0.18 seconds. The hour, 10 A.M., is a convenient representation of the daily performance: any other hour would give practically the same result.

The Boston Time Ball was dropped automatically by telegraph at noon 286 week days. The corresponding figure for the preceding year (omitted from the previous report) was 289 week days. The practice of dropping by hand when the telegraphic connections fail has been discontinued. The number of such failures is still greater than it ought to be and measures are now being taken to reduce it.

There is no record of dropping at the wrong time during the two years. For one day this year the record is uncertain, however; while on one day last year the ball started prematurely, but was caught part way down, raised, and then slowly lowered by hand as a sign that no reliable dropping had occurred.

Telegraphic Announcements. — The telegraphic distribution of astronomical intelligence has been continued during the year under the management of Mr. Ritchie. Announcements have been made of the discovery of nine asteroids and five comets, concerning which twelve cable messages have been received and two have been despatched. The respective numbers of telegrams circulated in this country concerning asteroids and comets are 109 and 173.

Publications. — The increase of Observatory funds has permitted the publication in the Annals of much material which would otherwise have remained unpublished or have been communicated in an abbreviated form to periodical works. Hence the number of these contributions to periodicals is now comparatively small.

Arrangements have been made with several other institutions for coöperation in the publication of some of their observations. The publication of the Pike's Peak observations of the U. S. Signal Service has been mentioned in describing the work of the Boyden Fund. The Bulletin of the New England Meteorological Society for the successive months of 1888 has also been printed with the aid of the Observatory, and will ultimately appear as part of its Annals. The publication of the observations made in 1887 at the Blue Hill Meteorological Observatory is also in progress in pursuance of the system of coöperation above described.

The complete publications of the year are as follows: —

Forty-second Annual Report of the Astronomical Observatory of Harvard College.

Henry Draper Memorial. Second Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory. Edward C. Pickering, Director. With two plates. Cambridge, 1888. Reprinted in Nature, xxxviii. 306, and Memorie della Società degli Spettroscopisti Italiani.

Boyden Fund. Circular No. 3. Observations of Temperature and Rainfall.

Annals of the Astronomical Observatory of Harvard College. Volume XVIII. Nos. III., IV., V., entitled respectively Photometric Observations of Asteroids, by Henry M. Parkhurst; Total Eclipse of the Moon, January 28, 1888; and Total Eclipse of the Sun, August 29, 1886.

Comet-Meteor Radiants. By O. C. Wendell. Astronomische Nachrichten, cxviii. 175.

Occultations observed during the Lunar Eclipse of January 28, 1888. By O. C. Wendell. Ibid. cxviii. 309.

Observations of Planet (80) Sappho. By O. C. Wendell. Ibid. cxix. 299.

Orbits of Meteors. By O. C. Wendell. Sidereal Messenger, vii. 37.

Orbit of Comet 1888 *a* (Sawerthal). By O. C. Wendell. Ibid. vii. 216.

The Apparent Instability of Stars near the Horizon (Sternschwanken). By Arthur Searle. Astronomische Nachrichten, cxx. 109.

EDWARD C. PICKERING, *Director*.

FORTY-FOURTH

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REPORT.

To the President of the University:

Sir, — The Observatory has suffered a severe loss by the death of one of its oldest friends, the last survivor of those who took an earnest part in its establishment. The active aid rendered by Mr. J. I. Bowditch in every attempt to extend our work, during the entire career of the Observatory, has done much to bring it to its present condition.

A gift of fifty thousand dollars was received last summer from Miss C. W. Bruce of New York, for the construction of a photographic telescope of novel form. The importance of this gift will be explained below. If successful, it will materially affect the entire plan of work of this Observatory.

By the continued aid of Mrs. Draper, with that of the Boyden Fund, an expedition has been sent to Peru, and will thus enable some of the most important investigations made here to be extended so as to include the southern stars. The plan of maintaining two stations, one in the northern hemisphere and one in the southern, will permit all our researches to include the entire sky, and thus give them a completenesss unattainable at any single station. A second expedition to southern California gives us a mountain station under climatic conditions much superior to those of the eastern portion of the United States, and promises to be a satisfactory solution of the problem contemplated by Mr. Boyden in his will. All of these plans greatly increase the work accomplished by the Observatory and also its expenditures. Notwithstanding the large addition to its resources, the entire income has been expended in almost all of its departments. The institution is therefore much larger, but cannot be regarded as richer in the sense of being able to indulge in luxuries, or even to supply some obvious needs. The increased amount of work renders more urgent certain wants of the Observatory which have been pointed out in past years. The most important of these is a new fire-proof building. More room is constantly required, but no funds are available for this purpose. In order to replace the records and other property now contained in the main building, which might easily be destroyed in a few minutes by fire, the sum of at least one hundred thousand dollars would be required.

Should such a calamity occur, the Director feels that he should not be held responsible, after pointing out this danger year after year. In at least one case a large gift to the Observatory was imperilled when the donor learned of the danger from fire. A gift of ten or even of five thousand dollars would partially remedy this difficulty by permitting the erection of a small brick building in which the photographs and manuscripts could be safely stored. Such a building would form a part of the large structure which will be imperatively needed in the near future. If the income of the Observatory is expended for this purpose, a corresponding part of the work described below must be abandoned or so much delayed as greatly to diminish its value.

Publication of results is the only certain way to secure observations permanently from destruction. This work is now being vigorously pursued. During a large part of the year as many as five volumes of Annals have been simultaneously in course of publication.

Observatory Instruments.

East Equatorial. — This instrument has been provided with six new eyepieces, and two square bar micrometers made of tinfoil mounted upon glass by Professor Rogers. The observations made during the year are as follows: 22 eclipses of Jupiter's satellites have been photometrically observed, making in all 430 since 1877; the comparison stars of S *Cephei* were observed on one night with the wedge photometer; this photometer has also been used in the observation of three asteroids, (4) Vesta on 13 dates, (7) Iris on 23, and (1) Ceres on 16; and in the observation on 30 dates of zones of stars from the Durchmusterung. The following comets have been observed for position: 1888 V. on 8 dates; 1889 I. on 17; 1889 II. on 4; and the comet discovered by Brooks on July 6, on 10 dates. Companion *c* to the comet last mentioned was observed on 2 dates. At the request of the discoverer, the asteroid (287) Nephthys, found by Professor Peters, was observed on 3 nights. Since February 25, 1889, each of 16 circumpolar variable stars has been observed about once in two weeks by Argelander's method and by estimate; the total number of these observations is 206. There are also 11 series of observations of the comparison stars of these variables, made with the wedge photometer and by estimate. A new variable discovered by Peters has been observed photometrically 5 times, and 7 observations were made by Argelander's method of a variable discovered by photographic means in the cluster G. C. 3636. These observations, except those of Jupiter's satellites, have been made by Mr. Wendell.

Meridian Circle.—The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The catalogue of the zone from 50° to 55° of north declination is completed and the first half of it has been forwarded, ready for printing, to the Astronomische Gesellschaft. The second half will soon be sent. The discussion of the systematic errors of the various catalogues which contain stars between the declinations +49° 50′ and +55° 10′ has also been finished and tables have been prepared for the reduction of these catalogues to the system of the Astronomische Gesellschaft. The entire discussion of the proper motions will soon be ready for publication. It will occupy about 200 printed pages. Less progress has been made in the reduction of the observations made from 1879 to 1883, as this work has been considered less urgent than that on the zone observations just mentioned.

The observation of the southern zone comprising the declination from —9° 50′ to —14° 10′ has been continued through the year by Professor Searle, assisted by Mr. Dunne. The number of nights of observation is 143; the total number of observations is 8565, distributed as follows: 287 relating to circumpolar stars, 1024 to fundamental stars, 6889 to zone stars, and 365 to stars incidentally observed, more particularly to a series of comparison stars for the asteroid (12) Victoria, observed at the request of Dr. Gill. Continuous progress has been made in the reductions, which cannot, however, be prevented, with the present force of computers, from falling considerably behind the observations, in the manner well known to be customary, and perhaps inevitable, in undertakings of this kind.

Horizontal Telescope.—The twelve-inch horizontal telescope described in the last report was completed so that it was ready for measuring the light of all stars brighter than the fourteenth magnitude. The pressure of other work, however, prevented regular observations from being undertaken with it. It is now being used by Mr. G. E. Hale in an investigation on the solar spectrum.

HENRY DRAPER MEMORIAL.

The first research on the spectrum of over ten thousand of the brighter stars is now nearly completed and is partially in print. The photographs required for the second research on the spectrum of the fainter stars are also nearly complete. The eleven-inch telescope has been in constant use throughout nearly every clear night in photographing the spectrum of the brighter stars. This work is approaching completion for all stars bright enough to be photographed by means of our present appliances, with the large dispersion now employed.

Good progress has also been made with the classification of the spectra, and the study of the slight differences in different stars. By the use of an improved process for staining plates with erythrosin, the yellow and green portions of the spectrum, even of the fainter stars, can be advantageously studied. Numerous experiments have been made with a device for measuring the approach and recession of stars, by means of an achromatic prism in front of the object-glass. Several peculiar spectra have been studied, especially that of ζ Ursae Majoris. The periodic doubling of its lines seems to be due to the rotation of two components too close to be distinguished by direct observation. The detection of bright lines in one of the stars in the Pleiades suggests a possible explanation of the legend that seven stars were formerly visible in this group.

During last spring an expedition was sent to Peru in charge of Mr. S. I. Bailey, assisted by Mr. M. H. Bailey. A station was selected on a mountain about six thousand feet high and about eight miles from Chosica. All supplies for the station, including water, must be carried by mules for this distance. Two frame buildings covered with paper have been erected, one for an observatory, the other for a dwelling house. Since May 9 the Bache telescope has been kept at work during the whole of every clear night. 1236 photographs have been obtained. The plan proposed will cover the sky south of —15° four times, once with photographs of spectra having an exposure of an hour which will include stars to about the eighth magnitude; secondly, with an exposure of ten minutes giving the brighter stars; thirdly, with charts having an exposure of one hour, permitting a map of the southern stars to the fourteenth magnitude inclusive; and fourthly, with charts having an exposure of ten minutes, including stars to about the tenth magnitude. The weather for the first four or five months was excellent, being clear nearly every evening. Fogs and cloud which often covered the adjacent valleys and the city of Lima did not reach to the top of the mountain. The cloudy season is now beginning and the work will be more interrupted. But nearly one half of the entire programme has already been carried out. A large number of interesting objects have been detected, among others several stars having bright lines in their spectra. Including the photometric work described below, the amount of material so far collected is unexpectedly large.

BOYDEN FUND.

The climate of southern California seems especially favorable to the undertaking desired by Mr. Boyden. An expedition under the direction of Professor William H. Pickering was accordingly sent in

November, 1888, to the summit of Wilson's Peak, in the vicinity of Los Angeles. In order that as much useful work as possible might be accomplished, the thirteen-inch telescope and the eight-inch telescope now in Peru were sent to Willows, California, where the Total Solar Eclipse of January 1, 1889, was successfully observed. Forty-seven photographs were obtained by the party during the three minutes of totality, and the instrumental equipment was much superior to any previously used for such a purpose. It was not until May 11, that the large telescope was successfully mounted on Wilson's Peak, by Messrs. E. S. King and Robert Black, but since then it has been kept at work throughout every clear night. The number of photographs obtained is 1155. The objects photographed are selected from a list of 625 double stars, 143 clusters and other celestial bodies, such as the Moon and planets. As these same objects have been repeatedly photographed at Cambridge with the same instrument, an accurate comparison of the atmospheric conditions of the two places may be made. It will of course be impossible to derive a final conclusion until the observations have extended over at least a year, but the evidence already secured shows that in summer results can be obtained at Wilson's Peak which cannot be obtained here. The difference is very pronounced for such objects as the markings on Jupiter. Clusters like that in Hercules are well resolved, so that the individual stars are easily measured, which cannot be done with the best Cambridge photographs. As a test-object the sixth star in the trapezium of the Orion nebula is clearly photographed for the first time. A new variable star has been discovered in the midst of the cluster G. C. 3636. A beginning has been made of the measurements of the position and brightness of the double stars, and it is hoped to extend this work to the clusters, and thus furnish an extensive addition to this department of micrometric astronomy.

Much experimental work has also been done at Cambridge, as is shown by the fact that nearly a thousand photographs have also been taken there. Moreover, the expedition to Peru is largely supported by the Boyden Fund. The meridian photometer will be used to extend two large series of observations to the south pole. These are the Harvard Photometry, and the zones used in the revision of the Durchmusterung. This work will furnish photometric magnitudes of stars as bright as the ninth magnitude in all parts of the sky. The Messrs. Bailey have observed 67 series, one of them including 293 stars. In all, during less than six months, about 6700 stars have been observed, which have required 26,800 settings.

THE BRUCE PHOTOGRAPHIC TELESCOPE.

For the last six years experiments have been in progress here on the use of a photographic doublet in the preparation of maps of the stars. The eight-inch telescope now in Peru is of this form and was mounted here in 1885. Since then 4500 photographs have been taken with it. With an exposure of an hour twice as many stars can be photographed as are visible with a telescope having an aperture of fifteen inches, and as many stars as can be photographed in the same time with a telescope of the usual form having an aperture of thirteen inches. Moreover with a doublet a portion of the sky covering twenty-five square degrees can be photographed with good definition, while only three or four degrees can be covered equally well with telescopes of the usual form. The time required to photograph the entire sky will be reduced in the same proportion. With a doublet each hemisphere could be covered in one year with eight hundred plates. In 1885 it was proposed to photograph the entire sky with the eight-inch telescope, enlarging the plates three times. The results would resemble in scale and size the charts of Peters and Chacornac. The generous aid of Miss Bruce mentioned above will permit this result to be attained in the original photographs, without enlargement. A contract has been made with Messrs. Alvan Clark & Sons for a telescope having an aperture of twenty-four inches and a focal length of eleven feet. Meanwhile nineteen foreign observatories have united in an Astrophotographic Congress to prepare a map of the stars to the fourteenth magnitude with telescopes of the usual form having apertures of thirteen inches. The plans have been matured with great care and skill. The courteous reference to the Bruce Telescope and its proposed work by Admiral Mouchez shows that both plans can be carried out without disadvantageous duplication. Doubtless each plan will possess certain advantages over the other. The Bruce telescope will be especially adapted to studying the very faint stars. It is hoped that those of the sixteenth magnitude and fainter can be photographed. Its principal use will probably be for the study of the distribution of the stars, for complete catalogues of clusters, nebulae, and double stars and for the spectra of faint stars. The amount of material accumulated will be enormous and the best method of discussion will form a very difficult and important problem.

MISCELLANEOUS.

Library.—The library of the Observatory has been increased during this year by the addition of 484 volumes and 336 pamphlets. The relatively small increase in pamphlets is explained by the fact that large numbers of pamphlets have been bound in volumes. An actual count of the works contained in the library on November 1, 1889, showed the total numbers of volumes and pamphlets to be respectively 6456 and 6125. The corresponding numbers found by adding the increase above stated to the totals given in the report of the University Librarian for last year are 4583 and 7911.

Time Service. — The standard time signals were sent by the Ballou clock No. 103 until August 21, since which date they have been sent by the Bond clock No. 394. No. 103 was then used as the normal clock while the sidereal clock, Frodsham No. 1327, commonly depended on for that service, was cleaned, and while the amount of mercury in the pendulum of No. 1327 was altered to secure better compensation for temperature. The average amount of the error of the time signals at the time of observing star transits has been $0^{s}.32$, the average interval between the times of these determinations being 2.9 days. The average error of the signals at 10 A.M. has been $0^{s}.27$, the number of clock comparisons taken for the purpose of keeping the error of the signals small being about 520. The average change in the daily rate from each day to the next has been $0^{s}.23$.

The Boston Time-Ball was dropped at noon on 290 week days, 287 times automatically by telegraph. When the telegraphic communication is known to be faulty, the ball is not hoisted at all; but three times such faults started the ball prematurely. Each time it was quickly caught and held by the hand-brake until the proper moment for release. Once it was dropped five minutes early, but immediately rehoisted and dropped again at the proper time.

Telegraphic Announcements. — The telegraphic distribution of astronomical intelligence has been continued during the year under the management of Mr. Ritchie. Announcements have been made of the discovery of seven asteroids, six comets, a suspected change in the crater Plinius, the light of Saturn's rings, and the separation of comet Brooks. Thirteen cable messages have been received, and seven have been despatched, while the distribution in this country has been effected by telegrams in number as follows: asteroids, 81; comets, 293; and other notices, 19.

Publications. — A considerable number of Volumes of the Annals of the Observatory have been carried to a greater or less extent through the various stages of publication. It has already been mentioned that the Catalogue of the zone from the declination of +49° 50′ to that of +55° 10′, which will form Volume XV., Part II., has been completed and sent to Germany for publication. Of Volume XVIII., Nos. VI., VII., VIII. and IX. have appeared during the year. Their subjects are as follows: Detection of New Nebulae by Photography; A Photographic Determination of the Brightness of the Stars; Index to Observations of Variable Stars; Meridian Circle Observations of Close Polar Stars. A subsequent memoir will form No. X., and will complete the volume. Volume XIX., Part I., was published during the year. It contains a summary of the meteorological observations made at the Observatory from its foundation to to the end of 1888. Volume XX., Parts I. and II., has also been published. It contains the meteorological observations made during 1887 and 1888 at the Blue Hill Observatory, and has been prepared pursuant to the system of co-operation with that institution described in the last report. Volume XXI., Part I., contains the observations collected by the New England Meteorological Society, between which and this Observatory a similar system of co-operation exists. This volume is in type and nearly ready for printing. Volume XXII. requires only the final corrections before it is printed. It contains the observations made on Pike's Peak by the United States Signal Service from 1874 to 1888 inclusive, and is published in conformity with the agreement mentioned in the last report. Volume XXIII. will contain the description of the meridian photometer used from 1882 to 1888, and a discussion of its work. Of this volume 13 pages are in type. Volume XXIV. contains the results obtained with this photometer from the zones of stars from the Durchmusterung, which formed the principal subject of its work, as well as a catalogue of about 4000 other stars. Of this volume 146 pages are in type. Volume XXV. has not yet been undertaken. Volume XXVI. contains the description and discussion of the photographic work first undertaken to carry out the objects of the Henry Draper Memorial, and its first chapter, comprising 8 pages, is in type. Volume XXVII. contains the catalogue of magnitudes and spectra of stars described above as a portion of the Henry Draper Memorial. Proof of this has been received from the printers as far as page 109.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-third Annual Report of the Astronomical Observatory of Harvard College. Reprinted in part in the Observatory. xii. 111.

Henry Draper Memorial. Third Annual Report of the Photographic Study of Stella Spectra conducted at the Harvard College Observatory. Edwin C. Pickering, Director. Cambridge, 1889. Reprinted in Nature, xl. 17.

A Large Photographic Telescope.

Bruce Photographic Telescope.

Beobachtungen des veränderlichen Sterns Z Sagittarii. By E. C. Pickering. Astronomische Nachrichten, cxxi. 188.

Stars having Peculiar Spectra. By E. C. Pickering. Ibid. cxxii. 159.

Photographic Chart of the Heavens. By E. C. Pickering. The Observatory, xii. 375.

Atmospheric Economy of Solar Radiation. By Arthur Searle. Proc. Am. Acad. xxiv. 26.

Physical Aspect of the Planet Mars. By W. H. Pickering. Science, xii. 83.

Soaring of Birds. By W. H. Pickering. Ibid. xiii. 31, 151, 245.

Total Solar Eclipse of Aug. 1887. By W. H. Pickering. The Observatory, xii. 213.

Determination of the Sensitiveness of Photographic Plates. By W. H. Pickering. International Annual of Anthony's Photographic Bulletin, ii. 185.

Total Solar Eclipse of Jan. 1889. By W. H. Pickering. Sidereal Messenger, viii. 337.

The Orion Nebula. By W. H. Pickering. Knowledge, xii. 191; xiii. 247.

Ephemeris of Comet 1889 I. for Jan. and Feb. 1889. By O. C. Wendell. Sidereal Messenger, vii. 82.

Ephemeris of Comet 1889 I. for March, 1889. By O. C. Wendell. Sidereal Messenger, vii. 132.

Ephemeris of Comet 1889 I. for April, 1889. By O. C. Wendell. Sidereal Messenger, vii. 225.

Ephemeris of Comet 1889 II. for June, 1889. By O. C. Wendell. Sidereal Messenger, vii. 266.

Observations of Comet 1888 I. By O. C. Wendell. Astronomische Nachrichten, cxx. 235.

Observations of Comet 1888 III. By O. C. Wendell. Astronomische Nachrichten, cxx. 251; Astronomical Journal, viii. 135.

Elements of Comet 1889 I. By O. C. Wendell. Astronomische Nachrichten, cxxi. 239.

Observations of Comet 1889 II. By O. C. Wendell. Astronomische Nachrichten, cxxi. 319; also, Astronomical Journal, ix. 8.

Observations of Comet 1889 d. By O. C. Wendell. Astronomische Nachrichten, cxxii. 217; also, Astronomical Journal, ix. 69.

EDWARD C. PICKERING, *Director.*

FORTY-FIFTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING OCTOBER 31, 1890.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
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REPORT.

To the President of the University:

Sir, — The urgent need at the Observatory of a fire-proof building has been pointed out in several successive annual reports. The last year has brought to the Observatory about nine thousand photographic plates, — some taken in Peru, some in California, and some in Cambridge. The total number of these plates is about twenty-seven thousand. All of them are stored in wooden buildings, where they might be destroyed by fire in a few minutes. They represent nearly the entire sky from the north to the south pole, the greater portion being covered several times, and they show not only the positions of the stars, but also their spectra. A large part of the charts and nearly all of the spectra are unique and have not been photographed elsewhere. Accordingly, in case of fire, future astronomers wishing to study changes in the stars would be obliged to begin with 1891 instead of being able to carry their work back in many cases to 1885. Even the weight of the plates is becoming a source of danger to the main building of the Observatory, as its floors are not constructed to carry heavy loads. Besides the photographs, a large amount of original manuscript, representing observations extending over a dozen years, is liable to destruction. This danger would be avoided by publication in the case of the manuscripts, but only partially in the case of the photographs. Accordingly excellent progress in publishing has been made during the last two years. But even here we are stopped by the expense and are obliged to delay until the interest of the publishing funds has accumulated. Otherwise, several additional volumes could be at once undertaken. The library is one of the most extensive and complete in astronomical works in the United States, and if destroyed could not be easily replaced. Finally, the instruments are delicate and valuable, although representing a small sum compared with the photographs and manuscripts.

In the last annual report reference was made to the loss sustained by the Observatory of one of its oldest friends, Mr. J. I. Bowditch. Since then I have learned that to his many gifts to the Observatory he has added another, — a legacy of twenty-five hundred dollars.

OBSERVATORY INSTRUMENTS.

East Equatorial. — The observations made during the year are as follows: 21 eclipses of Jupiter's satellites have been photometrically observed, making in all 451 since 1877. The following comets have been observed for position: 1889 I. on 1 date; 1889 V. on 31, comprising 34 observations; companion to 1889 V. on 3; 1889 VI. on 7; 1890 I. on 3; the comet discovered by Brooks, March 19, on 12 dates; the comet discovered by Coggia, July 18, on 4 dates; the comet discovered by Denning, July 23, on 2 dates; and D'Arrest's comet, rediscovered by Barnard on October 6, on 1 date. The systematic observation of 17 circumpolar variables has been continued, as in the previous year, and one recently discovered by photography has also been added to the list. Each star is observed about once in two weeks by the Argelander method and by direct estimation of magnitudes. The total number of these observations during the last year is 381 relative estimates by the Argelander method and also the same number of estimates of magnitude, with the large telescope. Relative estimates of these variables were obtained at the same time with the finder, if the stars were visible in it; 37 series of relative estimates of comparison stars for these variables have also been made, and 10 series of photometric measurements of the same stars with the wedge photometer. The wedge photometer has likewise been used in the observation of 22 series of zones from the Durchmusterung, comprising 838 stars.

In order to facilitate the decision of questions relating to the identity of stars observed with the meridian circle in the zone +50° to +55°, 70 observations of the relative positions of stars have been made with the Equatorial. In addition to the above, observations have been made of several other miscellaneous objects. These observations, except those of Jupiter's satellites, have been made by Mr. Wendell.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The printing of the zone catalogue, as shown under the head of Publications, is far advanced. The manuscript of the volume which is to contain the separate results of previous observations of the stars of the Harvard College zone reduced to 1875.0, with a discussion of the systematic errors involved in the reduction to the system of the Astronomische Gesellschaft of the various catalogues employed, together with the resulting proper motions, is ready for the printer. The time required in preparing this volume has allowed little progress to be made in the reduction of the observations made from 1879 to 1883.

The observation of the southern zone comprising the declinations from —9° 50′ to —14° 10′ has been continued throughout the year by Professor Searle, assisted by Mr. Dunne. The number of nights of observation is 111; the total number of observations is 6955, distributed as follows: 214 relating to circumpolar stars, 777 to fundamental stars, 5768 to zone stars, 70 to variable stars, and 126 to stars incidentally observed. Continuous progress has been made in the reductions, and forms have been arranged for the publication of the observations. A few series of observations have been entered in these forms.

West Equatorial. — The six-inch equatorial mounted in the West Dome has been used in testing the new method proposed by Professor Michelson for measuring double stars by means of diffraction images. Mr. W. M. Reed has also used it in an investigation of the light curves of variables of long period. A large part of the work has been done during the last month, but in all 218 observations have been obtained on 40 nights.

HENRY DRAPER MEMORIAL.

During the past year 1309 photographs have been taken with the Bache telescope at the station near Chosica in Peru. Nearly all of them relate to the region south of —20°. Photographic charts having an exposure of ten minutes and showing all stars to the twelfth magnitude have been obtained, comprising nearly the entire region. Charts with an exposure of sixty minutes, showing stars to the fourteenth magnitude, cover about one half of the region. Spectra with an exposure of ten minutes, including stars of the sixth magnitude, cover nearly the entire region; and spectra with an exposure of sixty minutes, including stars of the eighth magnitude, cover about one half of the same region.

An instrument like the Bache telescope, having a photographic doublet for an objective, is capable of collecting so large an amount of useful material that Mrs. Draper decided to have constructed a second instrument of the same dimensions. This was accordingly mounted on the Observatory grounds and has been kept at work every clear night until daybreak since September 27, 1889. 2157 photographs have so far been taken, including charts with exposures of ten minutes, covering the sky north of —20°. By placing over the objective a prism of small angle, the spectra of very faint stars have been obtained even when they were as faint as the tenth magnitude.

Even red stars can be photographed in this way, and many objects having peculiar spectra now come within the reach of photography. Thus twenty-nine spectra of the fourth type have been obtained of which six, namely, DM. +14° 2048, A. G. C. 16937, 18947, 20554, 29232, and 30526 (π, Gruis), are new. The variable star U Hydrae belongs to this class. Spectra of fifteen planetary nebulae have been photographed. The hydrogen line, F, has been shown to be bright in eight stars, δ Centauri, μ Centauri, η Centauri, H. P. 1124, 3747, A. G. C. 17717, 18859, and χ Ophiuchi; the last has also other bright lines. Photographs have been obtained of all of the stars known to belong to that remarkable class discovered by Rayet, in which the spectrum consists mainly of bright lines. They number twenty-eight, and thirteen of them have been discovered in the present investigation, three during the past year. Their photographic spectra generally resemble closely those of the planetary nebulae. The hydrogen lines are shown to be bright in thirty variable stars of long period, namely: R Andromedae, o Ceti, U Ceti, R Tauri, R Aurigae, U Orionis, R Lyncis, L_2 Puppis, R Carinae, S Hydrae, R Leonis, R Ursae Majoris, R Corvi, T Ursae Majoris, R Virginis, S Ursae Majoris, U Virginis, R Hydrae, S Virginis, R Camelopardalis, R Bootis, S Coronae, U Herculis, R Draconis, R Ophiuchi, T Herculis, χ Cygni, T Cephei, R Aquarii, and R Cassiopeiae. This peculiarity of the variable stars furnishes a means of discovering them. Seven new variable stars have been found in this way, namely: DM. +48° 2942, DM. +33° 470, A. G. C. 18770, A. G. C. 22855, and the stars whose approximate positions for 1900 are in R. A. $1^{h.}$ $55.1^{m.}$, Dec. +56° 15′, R. A. $4^{h.}$ $37.1^{m.}$, Dec. —38° 26′, and R. A. $20^{h.}$ $9.4^{m.}$, Dec. —39° 29′.

The photographic charts mentioned above generally permitted the variability of these objects to be confirmed at once without waiting for confirmation visually. Every year, by the accumulation of additional photographs, this can be done more readily. Besides these stars about forty other stars have been suspected of variability owing to their spectra, and photographs of the regions containing them are taken every few days. A careful examination is made by Mrs. Fleming of all the photographs taken with the eight-inch telescopes in Cambridge and Peru, and has led to the discovery of about a hundred new third-type stars besides the objects named above. Mrs. Fleming has also had charge of the computation involved in Volumes XXVI. and XXVII. described below, and has prepared a large part of them for the press.

The detailed study of the spectra of the brighter stars with the eleven-inch telescope has been continued. Photographs have now been obtained, 845 during the past year, of nearly all the stars visible in this latitude and sufficiently bright. A beginning has been made of the description of these spectra. The most interesting result has been the discovery by Miss Maury of a second star, β Aurigae, which is shown by the doubling of the lines in its spectrum at regular intervals to be a close binary. The period of revolution in this case is very nearly four days. 78 photographs have been obtained of the spectrum of this star, and 89 of ζ Ursae Majoris. Two of the large prisms have also been attached to the fifteen-inch equatorial, and 143 photographs of the spectrum of ζ Ursae Majoris and 26 of β Aurigae have been taken with this instrument during the morning hours after its use for visual purposes is over. One photograph of σ Herculis seemed to show that this star also was double, but it has not been confirmed, although numerous additional photographs have been secured. Some interesting photographs have been obtained of the spectrum of several metals in the Bunsen flame. A photographic determination of the position of the pole of the heavens was made by Mr. R. D. Upham with the fifteen-inch Draper reflector. This apparently furnishes a means of measuring precession and nutation directly.

Boyden Fund.

Work under this fund has been continued at three places: Harvard College Observatory, Wilson's Peak in Southern California, and Chosica in Peru. Professor William H. Pickering took immediate charge of the work at the Observatory. Much time was devoted to visual observations of the colors and markings of the planet Mars with the twelve-inch telescope. A number of the so-called canals were recognized, but only one of them was distinctly seen to be double. The best methods of photographic enlargement of astronomical objects have also been studied. Investigations, founded on observations made here and elsewhere, have been conducted with regard — first, to the meteorology of the globe, with particular reference to cloudiness and other phenomena affecting the choice of astronomical stations; secondly, to the fundamental principles of astronomical photography; thirdly, to the great nebulous region comprising a large part of the constellation Orion; fourthly, to the best form of standard light; and finally to other details of quantitative photometric work. As will be seen from the list of publications, portions of these investigations have appeared in various periodicals. Instruments and buildings have been planned and largely constructed for future use at Arequipa, Peru.

The station at Wilson's Peak was kept in operation until August, when the telescope was dismounted and sent to Cambridge to be transmitted to Peru. The advantages of the climate of Wilson's Peak are less marked than was anticipated; still, they have been sufficient to justify an attempt to purchase a suitable site there for a more permanent station. This attempt has not yet succeeded owing to uncertainties of title and other difficulties. If it should fail, other equally good locations in the same region can be secured. The photographs taken at Wilson's Peak have largely represented the Moon and the planets, particularly Mars, the more conspicuous permanent markings of this planet having been successfully photographed. An important accession to the white spot surrounding the southern pole was found by the photographs to have occurred between the nights of April 9 and 10. One of the most interesting discoveries has been that of the immense extent of the great nebulous region of Orion; many interesting photographs of double stars and clusters have also been obtained.

Good progress was made at the station near Chosica in Peru, maintained by the Draper and Boyden departments conjointly, until the approach of the cloudy season. The clouds gradually rose higher and higher until they covered the observatory. Accordingly, in November, 1889, the Messrs. Bailey visited various points along the coast, going as far south as Valparaiso, and passing some time in Pampa Central in the desert of Atacama, one of the driest points on the surface of the earth. Their observations led to the conclusion that no better place could be found than Arequipa, situated on the Mollendo railway, at an elevation of about eight thousand feet. It did not seem best to make the change until the clear season was over. They accordingly returned to Chosica and resumed work there until October, 1890, when the instruments were dismounted, and it is expected that observations will be continued early in November at Arequipa.

The observations of the southern stars with the meridian photometer are now approaching completion. 110 series, comprising 13,836 stars (including duplicates), have been observed. The number of photometric settings is 55,344.

Valuable aid was rendered to the expedition by various residents in Peru, especially by Hon. John Hicks, United States Minister to Peru, and by Señor J. L. de Romaña, of Arequipa, under whose supervision a very instructive series of meteorological observations was carried on at four stations: Mollendo, at the sea level; Arequipa, at the elevation of 7500 feet; Vincocaya, at the elevation of 14,600 feet; and Puno, at the elevation of 12,500 feet.

THE BRUCE PHOTOGRAPHIC TELESCOPE.

The disks of glass for the lenses of this instrument have not yet been received. The disk for the prism, which is twenty-five inches in diameter and three inches thick, arrived safely. It appears to be unusually free from defects and nearly colorless. The important gift by Miss Bruce of six thousand dollars, to be distributed among astronomers of all nations, should be mentioned here. It furnishes an example of using money so as to secure the greatest scientific return, which, it is hoped, will find many imitators.

MISCELLANEOUS.

Library. — The library of the Observatory has been increased during the year by the addition of 311 volumes and 856 pamphlets. The total number of volumes and pamphlets on November 1, 1890, were respectively 6767 and 6891.

Time Service. — The standard time signals have been sent mainly by the Bond clock No. 394. The errors have been abnormally large this year. Their average at the time of observing star transits has been $0^{s}.42$, the average interval between determinations being 2.4 days. The average error at 10 A.M. has been $0^{s}.37$, the number of clock comparisons being about 700. The average change in the daily rate from each day to the next has been $0^{s}.38$. On July 25, however, the error was uncertain for several hours on account of a defective performance of the Ballou clock No. 103, which was then sending the signals; and on February 19 no signals were sent on account of damage to the transmitting apparatus by lightning on the previous evening. A line following a new route near Harvard Square has improved the transmission of the signals.

The Boston Time Ball was dropped on 286 week days automatically by telegraph at noon. On two other occasions it started prematurely, but was immediately rehoisted, as a signal of incorrect dropping, and then slowly lowered.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued under the management of Mr. Ritchie. During the year telegrams concerning the discovery of eleven asteroids and five comets, and others relating to three orbits and to two positions of comets, have been sent out, requiring in all 278 telegrams and 14 cable messages.

Publications. — The printing of the zone catalogue of stars between the declinations +55° 10′ and +49° 50′ has proceeded as far as the right ascension 17^h, and, at the present rate of progress, should be finished in about six weeks. This catalogue forms the chief part of Volume XV., Part II., of the Annals of the Observatory. Volume XVIII. was completed during the year by the publication and distribution of its final section, No. X. This contains a discussion of meridian circle observations of stars near the south pole. The first portion of Volume XIX., Part II., is in type. It consists of a discussion of the zodiacal light by means of the observations made here during the last fifty years. Volume XXI., Part I., and Volume XXII., mentioned last year as nearly complete, were published during the year. These works contain the observations of the New England Meteorological Society for 1888 and the observations made on Pike's Peak by the United States Signal Service, 1874 to 1888. Volume XXI., Part II., will be published immediately. It contains the observations of the New England Meteorological Society for 1889, with essays by officers of the Society on climate and sea breezes. Of Volume XXIII., Part I., 121 pages are in type. This part contains a description of the observations with the meridian photometer in the years 1882 to 1888, inclusive. The printing of Volume XXIV. is completed. It contains the determinations obtained with the large meridian photometer of the brightness of stars from the Durchmusterung, and of a considerable number of miscellaneous stars. The total number of stars measured in this work is 20,982. Volume XXV. is not yet undertaken. Volume XXVI., Part I., is in type to page 138. It contains a description and discussion of the observations made with the Bache telescope during the years 1885 to 1889. The printing of Volume XXVII. is completed. It forms part of the Henry Draper Memorial, and contains a catalogue of the spectra of 10,347 stars, to be known as the Draper Catalogue. Volume XXX., Part I., which is also completed, forms a continuation of Volume XX., and contains meteorological observations made at the Blue Hill Observatory during the year 1889.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-fourth Annual Report of the Astronomical Observatory of Harvard College. Cambridge, 1890.

Henry Draper Memorial. Fourth Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory. Edward C. Pickering, Director. Cambridge, 1890. Reprinted in the Memorie della Società degli Spettroscopisti Italiani, xix. 88.

Circular on Aid to Astronomical Research. By Edward C. Pickering. Reprinted in Nature, xlii. 299; The Observatory, xiii. 286; Sidereal Messenger, ix. 329.

Observations of the Zodiacal Light made at Harvard College Observatory. By Arthur Searle. Astronomische Nachrichten, cxxiv. 405.

Comparison of Photographic Efficiency of Telescopes. By W. H. Pickering. Knowledge, xiii. 35.

The Great Nebula in Orion. By W. H. Pickering. Sidereal Messenger, ix. 1.

The Occultation of Jupiter, Sept. 3, 1889. By W. H. Pickering. Ibid. ix. 148.

Photographs of the Surface of Mars. By W. H. Pickering. Ibid. ix. 254.

Visual Observation of the Surface of Mars. By W. H. Pickering. Ibid. ix. 369.

Use of the Swing-back versus the Sliding-front. By W. H. Pickering. Anthony's International Photographic Annual, 1890, p. 252.

Comets of 1887–8. By O. C. Wendell. Sidereal Messenger, ix. 38.

Orbit of Comet 1890 I. By O. C. Wendell. Sidereal Messenger, ix. 89.

Observations of Comets 1887 V., 1888 V., and 1889 I. By O. C. Wendell. Astronomische Nachrichten cxxiii. 295; also, Astronomical Journal, ix. 91.

Transit of Comet 1889 V. over a star. By O. C. Wendell. Sidereal Messenger, ix. 134.

'Observations of Comets 1889 VI. and 1890 I. By O. C. Wendell. Astronomische Nachrichten, cxxiv. 113; also, Astronomical Journal, ix. 159.

An approximate solution of Euler's Equation for Parabolic Motion. By O. C. Wendell. Sidereal Messenger, ix. 176.

Observations of Comet 1886 VII. By O. C. Wendell. Astronomische Nachrichten, cxxiv. 363; also Astronomical Journal, ix. 191.

Observations of Comets 1889 I., 1889 V., Companion to 1889 V., Comet a 1890, Comet b 1890, and Comet c 1890. By O. C. Wendell. Astronomical Journal, x. 69.

Ephemeris of Comet a 1890. By O. C. Wendell. Sidereal Messenger, ix. 276.

Elements and Ephemeris of Comet a 1890. By O. C. Wendell. Sidereal Messenger, ix. 324.

Ephemeris of Comet c 1890, for October, 1890. By O. C. Wendell. Sidereal Messenger, ix. 374.

Spectra of δ and μ Centauri. By M. Fleming. Astronomische Nachrichten, cxxiii. 383; also, Sidereal Messenger, ix. 91.

New Variable in Caelum. By M. Fleming. Astronomische Nachrichten, cxxiv. 175.

Stars having Peculiar Spectra. By M. Fleming. Ibid. cxxv. 155.

Two New Variable Stars near the Cluster 5 M Librae. By M. Fleming. Ibid. cxxv. 157.

New Variable Star in Scorpius. By M. Fleming. Ibid. cxxv. 361.

Stars having Peculiar Spectra. By M. Fleming. Ibid. cxxv. 363.

New Variable Star in Sagittarius. By M. Fleming. Ibid. cxxv. 365.

Stars having Peculiar Spectra. By M. Fleming. Sidereal Messenger, ix. 379.

Transit Observations in Photography. By W. P. Gerrish. Sidereal Messenger, ix. 121.

FORTY-SIXTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING OCTOBER 31, 1891.

BY

EDWARD C. PICKERING.

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REPORT.

To the President of the University: —

Sir, — For several years past the Observatory has needed a fireproof building for preserving the large collection of photographs contained in the West Wing. This collection consists of nearly thirty thousand glass plates representing the entire sky from the north to the south pole, partly taken in Cambridge and partly in Peru; also a similar collection of the spectra of the stars, and of spectra on a much larger scale of the bright stars visible in Cambridge. These photographs show the condition of the sky from 1886 to the present time and form the only collection of the kind which exists. The building in which they are stored is of wood and if a fire broke out would be destroyed in a few minutes. Fortunately, there is now a prospect that this want may be supplied by the erection of a plain brick structure. Subscriptions to the amount of $7200 have been promised towards a fund of $10,000 which is the estimated cost of the required building.

It is hoped that the remaining $2800 can be secured before long and that the foundation can be laid early next spring, so as to protect the plates from danger at as early a date as possible.

Observatory Instruments.

East Equatorial. — The observations with this instrument have been partly photometric and partly micrometric. Twenty eclipses of Jupiter's satellites have been observed photometrically, making 471 since 1877. One of the eclipses observed this year belongs to the opposition of 1890–1891 and completes a series of 452 eclipses observed during a period of rather more than one revolution of Jupiter. This series will be separately reduced and published. The systematic observation of seventeen circumpolar variable stars of long period has been continued, as in last year. Special attention was paid to the stars when they were faint. The relative brightness of the stars was determined by Argelander's method and a direct estimation was also made in each case. The total number of observations is 560 by each of these methods. Relative estimates of brightness were also made with the finder when the star was not too faint. Seventy series of observations of the relative brightness of the comparison stars for these variables were made, and fourteen series of measurements with the wedge photometer. Twelve zones comprising 403 of the fainter stars contained in the Durchmusterung were observed with the same instrument, each star being measured three times. Besides other miscellaneous observations, micrometric measures have been made of the positions of all the fainter comparison stars of the circumpolar variables and of the following comets: Comet 1891 IV. on 7 dates; 1891 a on 3 dates; 1884 III. on 6 dates; 1891 d on 8 dates. All of the observations, except a part of those of Jupiter's satellites, have been made by Mr. Wendell.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The printing of the zone catalogue, as shown under the head of Publications, is completed, and the manuscript of the introduction to that catalogue is in the hands of the printer. The manuscript of three additional volumes, each of about 400 pages, has been prepared. Two of these volumes contain the journal of the zone observations, and the third contains the reduction to 1875.0 of all previous observations available for comparison with the zone catalogue, and a discussion of the results thus obtained for proper motion.

The observation of the southern zone comprising the declinations from —9° 50′ to —14° 10′ has been continued throughout the year by Professor Searle, assisted by Mr. Dunne. The number of nights of observation is 130; the total number of observations is 6220, distributed as follows: 255 relating to circumpolar stars, 853 to fundamental stars, 5080 to zone stars, 29 to variable stars, and 3 to stars incidentally observed. It appears probable that continuous observation will be unnecessary after April, 1892, as nearly all the zone stars will then have been observed twice, and many of them three times, if the work continues through the winter without interruption. The reductions have been regularly continued and provisional results have been obtained for the stars observed in the summers of 1888 and 1889.

West Equatorial. — Observations have been made with the six-inch equatorial mounted in the West Dome on 148 nights by Mr. W. M. Reed. The principal work has been the study by Argelander's method of the changes in the light of the variable stars of long period. 668 observations have been made of the 17 circumpolar variables mentioned above, 98 of other variables of long period, 245 of variables of short period, and 61 of new variables. About 840 comparison stars have been selected for 42 variables. Another important investigation has been on the use of a small prism attached to the centre of the object-glass. Each star is thus accompanied by an image about four magnitudes fainter than itself by which it is expected that the scale of photometric magnitude may be extended from the eighth to the twelfth magnitude. The relative brightness of the two images has been determined by four independent methods.

HENRY DRAPER MEMORIAL.

Three telescopes have been used continuously in this department of the Observatory, generally throughout every clear night. The eight-inch telescope closely resembles the Bache telescope and has a photographic doublet for an objective. 2505 photographs have been taken with it this year. Nearly one-half of the northern sky has been covered with charts having an exposure of ten minutes. A small prism attached to the objective forms faint images of the brighter stars and provides a means of determining the true brightness of the fainter stars. A prism covering the objective enables the spectra of the fainter stars to be photographed. Similar work on the Southern stars has been done in Peru with the Bache telescope, 1224 photographs having been taken. The examination of these plates by Mrs. Fleming has shown that eight variable stars, R Cancri, S Serpentis, R Herculis, S Herculis, R Cygni, R Aquilae, and V Monocerotis, in addition to the thirty previously announced, have the hydrogen lines bright in their spectra. Five new variables have been discovered during the year by means of this property. Bright lines are also seen in the spectra of R Coronae and g Herculis which apparently are not due to hydrogen. Two known variables, R Sculptoris and U Cygni, have been shown to be of the fourth type and two fourth-type stars have been discovered to be variable. The number of stars of the fifth type, that is, having bright lines in their spectra like those discovered by Wolf and Rayet, has been increased by nine. The total number now known of these objects is 37, 27 of which have been found at this Observatory. All of them are situated very near the central line of the Milky Way which fact has led to the detection of several previously unknown. The hydrogen line F was shown to be bright in ν Sagittarii and ν Cygni. DM. —12° 1172, hitherto supposed to be a star, is shown by the photographs to be a planetary nebula. Two stars, DM. —10° 513 and DM. —10° 5057, have spectra of the fourth type in which, however, the blue light is well shown so that they do not have the usual characteristic red color. Well marked spiral rays are visible in a photograph of N. G. C. 1566.

The number of photographs taken with the eleven-inch Draper telescope is 1089. Photographs have now been obtained of the spectra of all the stars visible in Cambridge and bright enough to bear the dispersion used with this instrument. A large number of photographs were taken of β Aurigae to determine the form of the orbit of this curious binary. During December, 1890, this star was followed throughout every clear night so that the period could be determined with precision by comparison with similar observations made in 1889. By moving the telescope in right ascension every twenty minutes several spectra were obtained on each plate. In all, 184 spectra of this star were photographed. 106 photographs were also taken of ζ Ursae Majoris to study the apparent irregularity in the time at which its lines are double. In 10 cases only are the lines certainly double. An interesting discovery was made by Mrs. Fleming, that the bright lines in the spectrum of β Lyrae change their position in a manner somewhat like the doubling of the dark lines in β Aurigae. The changes occur in the same period as the changes in light and appear to be very complex, but could, in general, be explained if we suppose the star to be a close binary; the spectrum of one component having bright, — the other, dark lines. A careful study of these changes has been made by Miss Maury and also of the spectra of the stars of the Orion type. A large number of charts have also been made of the vicinity of variable stars and of other peculiar objects, so that the parallax can be detected, if appreciable. To permit the prisms to be easily removed and replaced they have been counterpoised with a system of link-work which permits these changes to be made almost instantly without disturbing the equilibrium of the telescope. A large amount of work has been done on the measurement of the position of the lines in the stellar spectra and their conversion into wave-lengths. By the kindness of Mr. Edison, a dynamo of four horse power has been presented to the Henry Draper Memorial. This will greatly facilitate the study of terrestial spectra.

BOYDEN FUND.

The attempt to secure a suitable location for an observing station on Wilson's Peak in Southern California proved unsuccessful. A clear title could not readily be obtained for the land and the advantage of the situation as regards climate proved to be less than was at first anticipated. Although the air is extremely steady at certain times, clouds prevent observations during a large part of the winter and in the daytime the unsteadiness of the air would interfere seriously with solar work.

The expedition sent to Peru in 1889 under the direction of Mr. S. I. Bailey, having successfully completed the observations with the meridian photometer, returned to Cambridge with that instrument, which has been remounted here and will be used for a revision of the Harvard Photometry and for other photometric work. During the two years ending May 1, 1891, Mr. Bailey took 217 series of observations and made 98,756 photometric comparisons of about eight thousand southern stars. These include all the stars of the sixth magnitude and brighter south of —30° and all known catalogue stars in a series of zones 20′ wide at intervals of 5° in declination from —25° to —80°; also all known stars south of —80° and a miscellaneous list of variables, stars having peculiar spectra, etc. The reduction of these observations is nearly completed and their publication will be begun shortly. A large part of the work assigned to the Bache telescope has also been completed, and the instrument has been remounted at Arequipa where its work will be continued.

An expedition under the direction of Professor William H. Pickering left Cambridge in December, 1890, and established a station about three miles northwest of Arequipa, where the thirteen-inch equatorial has been mounted. This station has an elevation of a little over 8000 feet and has a nearly cloudless sky during a large part of the year. The air is remarkably steady, the images of the stars are small and round and the diffraction rings, seldom seen with large instruments, are clearly visible. Even with high powers the fluctuations of the images is very slight. In fact, at this station the limit to observation will probably be the size of the instrument instead of, as at other observatories, the condition of the air. Although the aperture of this instrument is only thirteen inches, it appears to be the largest refracting telescope in use in the southern hemisphere, while about thirty larger telescopes are mounted in the northern hemisphere. Since all of these instruments are north of +35° nearly one quarter of the entire sky, and that containing many objects of the greatest interest, has never been studied by a refractor of the highest grade. For both these reasons an excellent opportunity is afforded to add to astronomical discovery by the erection of a telescope of large size at this station. It is hoped that patrons of astronomy will consider the advantages of erecting a large telescope where it will be kept constantly at work, where the sky is clear a large part of the year, where the condition of the air is probably more favorable than at any other existing observatory, and where a large part of the sky could be examined for the first time under such satisfactory conditions.

Photographs have not yet been obtained with the thirteen-inch telescope, but it is hoped that its advantages for this kind of work will be as great as for visual observations. The expense of establishing this station was much greater than had been anticipated, since it was necessary to erect a stone dwelling-house for the observers. A considerable advance from the future income of the fund has accordingly been required. Important aid was rendered to the expedition by many residents in Peru. Mr. MacCord, Superintendent of the Mollendo Railway, should be especially mentioned for his hospitality to the observers who resided with him while the new house was in process of erection. Without his aid the establishment of the station would have been extremely difficult. Two interesting expeditions have been made in Peru. One of them by the courtesy of Mr. Anderson, American Minister to Bolivia, was to Tiahuanuco and the sacred islands of the Incas on Lake Titicaca and led to results of much archaeological interest. The other was to the summit of El Misti, a nearly extinct volcano about nineteen thousand feet high.

THE BRUCE PHOTOGRAPHIC TELESCOPE.

The two disks of glass for the flint-lenses of this instrument have reached here safely and appear to be of excellent quality. An accident to one of the disks of crown glass delayed its completion, but both of them are promised at an early date. Plans are being prepared for the mounting, and work on the instrument will begin as soon as the crown disks are received. The work of grinding and polishing the 24-inch prism to be used with this telescope has been completed during the year.

Various subsidiary investigations have been planned in connection with this instrument. For instance, the brightness of all stars photographed should be reducible to a uniform scale of magnitudes. A photographic transit instrument has been constructed which is moved automatically and photographs on a single plate all stars brighter than the sixth magnitude which cross the meridian during three hours. With this instrument it is expected to prepare a catalogue like the Harvard Photometry which will give the photographic magnitude of the bright stars on a uniform scale. A second investigation now well advanced will give the brightness upon the same scale of about forty thousand stars of the tenth magnitude. These stars are distributed throughout the entire sky so that one is in each square degree. Nearly three thousand of these stars have already been selected and almost all of them measured. About an equal number of brighter stars serves to reduce these observations to the same scale of magnitudes. Suitable photographs have been obtained of about one quarter of the entire sky, the whole of which will be photographed twice.

MISCELLANEOUS.

Library. — The library of the Observatory has been increased during the year by the addition of 262 volumes and 821 pamphlets. The total numbers of volumes and pamphlets on November 1, 1891, were respectively 7029 and 7781.

Time Service. — The standard time signals have been sent mainly by the Bond clock No. 394. The average error at the time of observing star transits has been $0^s.44$, the average interval between determinations being 2.5 days. The average error at 10 A.M. has been $0^s.38$, the number of clock comparisons being about 500. The average change in the daily rate from each day to the next has been $0^s.32$. In computing these figures the results for September 11 have been omitted since a large error occurred on that day owing to an accident to the clock. The signals were interrupted from September 14 to 17 owing to changes in the cable at the draw of West Boston Bridge. The Time Ball dropped correctly on 285 week days. It is probable that this department of the work of the Observatory will be abandoned shortly since similar signals furnished by the U. S. Naval Observatory are now offered to the public through the Western Union Telegraph Company.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued under the management of Mr. Ritchie. During the year telegrams concerning the discovery of nineteen asteroids and seven comets, and others relating to two orbits and to four positions of comets have been sent out, requiring in all 624 telegrams and 12 cable messages.

Publications. — The zone catalogue of stars between the declinations $+55^\circ\ 10'$ and $+49^\circ\ 50'$ has been printed, and the introduction has been sent to the printer, as stated above in describing the work done under the direction of Professor Rogers. This catalogue, with its introduction, will form Volume XV., Part II., of the Annals of the Observatory. Volume XIX., Part II., will be completed by the publication of a discussion of atmospheric refraction, the materials for which are derived from photographic observations. This work has been in progress during the year, but is not yet fully ready for printing. Volume XXI., Part II., mentioned last year as about to be published, has been printed and distributed. It contains the observations of the New England Meteorological Society for 1889, with essays by officers of the Society on climate and sea breezes. Volume XXIII., Part I., containing a description of the observations with the meridian photometer in the years 1882 to 1888, inclusive, has also been printed and distributed. Volume XXIV., containing the catalogue of 20,982 stars derived from these observations, which was printed last year, has since been distributed. Volume XXV. is not yet undertaken. Volume XXVI., Part I., which contains a description and discussion of the observations made with the Bache photographic telescope during the years 1885 to 1889, has been completed; and Volume XXVII., printed last year, has likewise been distributed. It forms part of the Henry Draper Memorial, and contains a catalogue of the spectra of 10,347 stars, to be known as the Draper Catalogue. Volume XXX., Part I., also printed last year, has been distributed, as has Part II., of the same volume, more recently printed. The whole volume forms a continuation of Volume XX., and contains meteorological observations made at the Blue Hill Observatory during the years 1889 and 1890, with a summary of observations for the five years ending with 1890. Volume XXXI., Part I., will soon appear, 130 pages being already in type. It forms the continuation of the observations of the New England Meterological Society, the publication of which was begun in Volume XXI.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-fifth Annual Report of the Astronomical Observatory of Harvard College. Cambridge, 1890.

Variable Stars of Long Period. Cambridge, 1891.

History and Progress of the Henry Draper Memorial. Extracted from the Annals of the Observatory, Volume XXVI., Part I.

Harvard College Observatory. A circular inviting subscriptions for the new fire-proof building.

A Possible Secondary Cause of the Phenomenon of Gegenschein. By Arthur Searle. Astronomische Nachrichten, cxxvi. 115.

Observations of Comets 1889 I., 1889 V., companion to 1889 V., Comet 1890 II., 1890 III., 1890 VI. By O. C. Wendell. Astronomische Nachrichten, cxxvi. 43.

Observations of Comet 1890 IV. By O. C. Wendell. Astronomische Nachrichten, cxxvi. 121; also, Astronomical Journal, x. 102.

Second series of Observations of Comet 1890 IV. By O. C. Wendell. Astronomische Nachrichten. cxxvii. 297; also, Astronomical Journal, x. 123.

Observations of Comet 1882 II. By O. C. Wendell. Astronomische Nachrichten, cxxvii. 293.

Observations of Comet 1889 I., Comet 1890 II., Comet 1890 III., Comet 1890 VI., and Comet a 1891. By O. C. Wendell. Astronomische Nachrichten, cxxvii. 297; also, Astronomical Journal, xi. 4.

Ephemeris of Comet 1890 VI., for November, 1890. By O. C. Wendell. Sidereal Messenger, ix. 419.

Ephemeris of Comet 1890 II., for December, 1890. By O. C. Wendell. Sidereal Messenger, ix. 465.

Orbit and Ephemeris of Comet 1890 IV. By O. C. Wendell. Sidereal Messenger, x. 35.

Ephemeris of Comet 1890 IV., for February, 1891. By O. C. Wendell. Sidereal Messenger, x. 102.

Ephemeris of Comet 1890 II., for March, 1891. By O. C. Wendell. Sidereal Messenger, x. 147.

Ephemeris of Comet 1890 II., for April, 1891. By O. C. Wendell. Sidereal Messenger, x. 201.

Orbit and Ephemeris of Comet a 1891. By O. C. Wendell. Sidereal Messenger, x. 288.

Ephemeris of Comet a 1891, for July, 1891. By O. C. Wendell. Sidereal Messenger, x. 368.

Stars having Peculiar Spectra, including New Variable Stars in Triangulum and Hydra. By M. Fleming. Astronomische Nachrichten, cxxvi. 117.

Stars having Peculiar Spectra. By M. Fleming. Ibid. cxxvi. 165.

Stars having Peculiar Spectra. New Variable Stars in Perseus, Triangulum and Hydra. By M. Fleming. Sidereal Messenger, x. 7.

Astronomical Expedition to Peru. By M. Fleming. Ibid. x. 105.

Stars having Peculiar Spectra. New Variables in Aquarius and Delphinus. By M. Fleming. Ibid. x. 106.

New Variable Star in Camelopardalis. By M. Fleming. Ibid. x. 152.

The New Red Star in Auriga. By M. Fleming. English Mechanic, liii. 50.

Objects of Interest on Spectrum Plates and Two New Variable Stars in Perseus. By M. Fleming. Astronomische Nachrichten, cxxvi. 163.

Stars having Peculiar Spectra. New Variable Stars in Aquarius, Delphinus, and Camelopardalis. By M. Fleming. Ibid. cxxvii. 5.

New Planetary Nebula. DM. —12° 1172. By M. Fleming. Sidereal Messenger, x. 240.

Stars having Peculiar Spectra. New Variable Star in Sagittarius, R. A. 19^h 51.8^m Dec. —42° 7′. By M. Fleming. Astronomische Nachrichten, cxxviii. 11.

Stars having Peculiar Spectra. New Variable Star in Lacerta. DM. +39° 4851. By M. Fleming. Ibid. cxxviii. 121.

Aid to Astronomical Research. By Edward C. Pickering. Reprinted in Sidereal Messenger, ix. 473.

Close Binary Stars. By Edward C. Pickering. Sidereal Messenger, x. 5.

A Fifth Type of Stellar Spectra. By Edward C. Pickering. Astronomische Nachrichten, cxxvii. 1.

The Discovery of Double Stars by Means of their Spectra. By Edward C. Pickering. Astronomische Nachrichten, cxxvii. 155.

Spectrum of β Lyrae. By Edward C. Pickering. Astronomische Nachrichten, cxxviii, 39. Reprinted in The Observatory, xiv. 341.

The Draper Catalogue. By Edward C. Pickering. Nature, xliv. 223.

EDWARD C. PICKERING, *Director*.

FORTY-SEVENTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING OCTOBER 31, 1892.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1892.

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REPORT.

To the President of the University: —

Sir, — By the death of Mr. George B. Clark of the firm of Messrs. Alvan Clark & Sons, the Observatory has lost a friend of many years standing. To his genius for mechanical devices, indomitable perseverance, and devotion to the interests of the Observatory, we are indebted for the success of many of our most useful instruments.

The most important matters to be considered in the following report are, the permanent establishment of an observing station in South America, where the difficulties depending on the unsteadiness of the air are almost entirely avoided; the construction of a new brick building, by which the photographs and manuscripts of the Observatory will be securely protected from the danger of fire; the approaching completion of the Bruce photographic telescope, and the observation by a variety of methods of the new star in Auriga.

Observatory Instruments.

East Equatorial. — While the photometric observation of the eclipses of Jupiter's satellites, and various kinds of micrometric work, as described below, continue to be carried on with this instrument, its principal use in recent years, like that of the West Equatorial, has become the systematic observation of variable stars. The stars chiefly observed are seventeen circumpolar variables of long period, but about seventy others also receive attention. The objects contemplated are, the formation of lists of comparison stars, proceeding by intervals of about half a magnitude from the maximum of each variable to its minimum or to the faintest star visible, as the case may be; the determination of the magnitude of each comparison star, at least by means of comparisons between it and others, and when practicable, by photometric methods; and finally, the observation of the variable star itself at intervals of two weeks or less. The lists of comparison stars are usually first selected by means of the West Equatorial, and revised by means of the larger instrument. The variable stars themselves are observed with the West Equatorial until they become too faint to be seen in it, when further observations of them are made with the East Equatorial. It is much to be desired that some observer, having a still larger instrument at his disposal, should systematically observe the stars which become too faint for the East Equatorial, until they have recovered sufficient brightness to make them again visible here.

The observations with the East Equatorial were made by Mr. O. C. Wendell, except 11 of the 29 eclipses of Jupiter's satellites measured photometrically during the year, which were made by the Director. The total number of eclipses photometrically observed since 1877 is now 500. More than 1000 observations of variable stars were made in pursuance of the plan above described, and lists of comparison stars for 37 variables were selected or revised. The new star in Auriga was compared with others 250 times, and was observed photometrically on 40 nights, during which 1344 separate settings of the photometer were made. The place of the new star was micrometrically observed on 3 nights, and several of the stars used in comparisons with it were also occasionally observed both with the photometer and the micrometer. The wedge photometer was used in 18 series of observations, comprising 1422 settings, for determining the brightness of 474 stars, selected from the Durchmusterung. Comet 1891 V. was observed for position on 5 nights; Comet 1891 II. on 4; and the comets discovered by Swift, Denning, Brooks, and Barnard, were similarly observed on 11, 2, 2, and 1 nights respectively. A number of miscellaneous observations, mostly relating to the stars near variables, were also made.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. During the year the catologue of the zone between the declinations +49° 50′ and 55° 10′ has been printed, and it is now ready for distribution. This work includes an elaborate introduction by Professor Rogers. The manuscript was sent to Germany for publication in accordance with an arrangement for coöperation between the Observatory and the Astronomische Gesellschaft, which also publishes an edition of this catalogue as a part of its general catalogue of stars to the ninth magnitude. The printing of another volume relating to the zone observations has made much progress, as mentioned below in describing the publications, and the journal of the observations has been carefully checked and in part recomputed during the year. It will occupy two additional volumes, which are expected to be ready for the printer in a few months.

The observations of the southern zone between the declinations —9° 50′ and —14° 10′ were so far completed during the spring by Professor Searle, with the assistance of Mr. Dunne, that the observations still to be made are only such as will be shown to be necessary by the progress of the reductions. Observations have therefore been suspended for the present. The number of nights of observation for the months of November, 1891, to May, 1892, inclusive, was 50; the total number of observations was 2132, of which 100 relate to circumpolar stars, 321 to fundamental stars, 1680 to zone stars, 29 to variable stars, and 2 to stars incidentally observed. The total number of observations made since the work began in April, 1888, is 25,922, and the corresponding numbers for the five classes of stars just mentioned are 961, 3329, 20,966, 128, and 538; the total number of nights of observation was 490. The work of reduction continues to make good progress. At present, it is directed chiefly to the completion of the reduction of the fundamental stars. An examination of their residuals for the first year has made evident a systematic variation dependent upon the declination of the stars, which it will be desirable to investigate for the whole series of observations.

Meridian Photometer. — Observations of the light of the southern stars with the meridian photometer were completed by Mr. Bailey on May 6, 1891. These measures give the brightness of about eight thousand stars south of —30° and continue the work contained in Volumes XIV. and XXIV. of the Annals, to the South Pole. The reduction of these observations is now approaching completion. Much attention has been paid to the discussion of the atmospheric absorption as many of the polar stars were observed at a large zenith distance. On the return of the photometer to Cambridge, preparations were made to resume work with it here. It was accordingly mounted in the west wing of the main building, so that the observer and recorder should be in a warm room in winter, instead of being exposed to the cold. Observations began November 3, 1891, and since then 105 series have been obtained, including 33,792 separate photometric comparisons; 36 of these series, including 10,216 comparisons, have been made by Mr. Bailey, the remainder were made by the Director. The principal work undertaken has been the reobservation of the stars of the Harvard Photometry. It is now about ten years since the completion of the observations contained in that work. The list for observation also includes a number of stars which are slightly fainter than the sixth magnitude, and such of the comparison stars for variables employed in the observations made with the East Equatorial as are brighter than the tenth magnitude. Numerous observations are also made of stars near the northern and southern horizon, to determine the atmospheric absorption, the southern stars also serving to connect the scale of magnitude with that derived from the observations in Peru. A large part of the reduction and discussion of these observations has already been made. On 16 nights measures were made of the new star in Auriga, and of 25 stars suitable for comparison with it. The numbers of settings in these cases were 600 and 532 respectively.

West Equatorial. — The principal observer with this instrument has been Mr. W. M. Reed. Mr. T. E. Powe has also made many observations with it. Mr. Reed has observed on 109 nights. In pursuance of the system above described for the observation of variable stars of long period, he has selected 285 comparison stars, and has made 803 observations of the brightness of stars to be compared with variables of long period; 458 observations of such variables themselves, and 62 of variables of short period. He has also used the prismatic photometer mentioned in the last report, as yet chiefly in the observations required for determining its constant. The new star in Auriga has also been frequently observed; 116 observations, involving 277 comparisons, have been made by Mr. Reed, who has also made 118 observations of the corresponding comparison stars. Mr. Powe has made 50 observations of the new star, and 54 of the comparison stars; also 249 and 388 observations respectively of variable stars of long and of short period, and 57 observations of stars for comparison with variables of long period. Mr. Reed, aided by Mr. Powe, has observed a number of auroras, and has investigated the parallax of two auroras by combining his observations with others made at Blue Hill and at Providence.

HENRY DRAPER MEMORIAL.

The number of photographs taken with the 8 inch Draper telescope is 2777. The number taken in Peru with the Bache telescope is nearly two thousand, of which 601 have been received in Cambridge. The examination of these plates has as usual led to the discovery of a large number of interesting objects. Ten variable stars, U Delphini, S Pegasi, T Aquarii, R Crateris, R Carinae, S Canis Minoris, S Carinae, R Ophiuchi, X Ophiuchi and Espin's variable star in Auriga in addition to the thirty-seven previously announced have the hydrogen lines bright in their spectra. Seven new variable stars have been discovered this year by means of this property. The number of stars of the fifth type has been increased by eight, making the total number now known of these objects, 45. The hydrogen line F was shown to be bright in the spectra of six stars in addition to those already known. Photographs have been obtained of the spectra of eight planetary nebulae showing bright lines. The spectrum of the nebula surrounding 30 Doradus is unlike that of other gaseous nebulae. The star A. G. C. 20,937 has a somewhat similar spectrum. Five stars have been shown to have spectra of the fourth type. All of these peculiarities have been detected by Mrs. Fleming except in the cases of one of the known variables, one of the planetary nebulae, and two of the stars of the fourth type, which were found by Mr. A. E. Douglass, in Peru, before the plates were sent to Cambridge.

The amount of valuable material accumulated with these instruments is continually increasing, and has proved useful in many cases in studying the history of newly discovered objects. The brightness for several years past of stars suspected of variability has been furnished to various astronomers. Plates have been sent to the Lick and Amherst Observatories and to the Smithsonian Institution for special investigations. From one of them a new variable star in Aries was discovered by Professor Schaeberle. It is hoped that this use of our plates may increase in the future. A large number of photographs were taken of the new star in Auriga. An examination of the older photographs showed that the region containing it had been photographed eighteen times from November 3, 1885 to November 2, 1891, and that it was then apparently fainter than the thirteenth magnitude. It appeared upon five plates taken between December 16, 1891, and January 31, 1892. After its discovery it was photographed on sixty-five chart plates and thirty-six spectrum plates, until April 6, when it became too faint to be visible in the encroaching twilight. All of these plates have been carefully studied and measured. 21 charts and 15 spectrum plates of this object have been taken since its reappearance in September, 1892. On these last plates, the spectrum is shown to resemble that of a planetary nebula.

Many photographs of the lunar eclipse of November 15, 1891, were taken both at Cambridge and at the Boyden observing station near Arequipa, Peru. The examination of these photographs for the detection of a possible lunar satellite led only to a negative result.

The number of photographs taken with the 11 inch Draper telescope is 996. They include 372 spectra of β Aurigae to determine the law of periodic doubling of the lines. 244 of these images show the lines double so that the separation can be measured. In like manner 208 spectra of ζ Ursae Majoris have been photographed, and in 49 of them the lines are separated widely enough to be measured. A similar study has been made of the new star in Auriga, of β Lyrae, of 11 Monocerotis, and of some other stars having peculiar spectra. Photographic charts have also been obtained of numerous variable stars, stars having large proper motion, clusters and stars having peculiar spectra to determine their parallax if it is perceptible.

BOYDEN DEPARTMENT.

In establishing the Fund that bears his name, Mr. Boyden desired to secure an astronomical station where the effects due to the atmosphere would be greatly diminished. This has now been successfully accomplished in the Harvard Station at Arequipa, Peru, where the effect of the air is no longer as heretofore the principal obstacle to progress in astronomy. Instead of this the limit is now the size and excellence of our instruments. A great advance would probably be made in our knowledge of the planets, and perhaps of the fixed stars, if a telescope of the largest size could be mounted under such favorable conditions.

This station has continued in charge of Professor W. H. Pickering. The instruments chiefly employed have been the 13 inch telescope, the 8 inch Bache telescope, and a photographic camera having an aperture of 2½ inches. The first of these instruments has been largely devoted to visual work, for which unusual advantages are afforded by the transparency and steadiness of the air at this station. Many interesting results have been derived from the observations made of the Moon and various planets. The observations of the Moon relate to Plato and other regions, which have been carefully examined, and also to the systems of bright streaks visible at full Moon. The markings of Mercury have been studied, and this investigation appears to confirm Schiaparelli's view that the rotation of Mercury on its axis occupies the same time as its revolution in its orbit. Although this planet appears to have no atmosphere, the markings upon it are very faint compared with those upon the Moon. Venus was micrometrically studied near its inferior conjunction with regard to its diameter, polar compression, and the refractive effect of its atmosphere. No permanent markings could be detected. An extensive series of observations was made upon Mars. The relative positions of 92 points upon its surface were determined by the micrometer. More than 40 minute black points were discovered, provisionally designated as lakes. The polar compression of the planet was measured, and appeared to be greater than that indicated by theory, which may be due to an excess of cloud in the equatorial regions. The presence of the dark and narrow streaks called canals by Schiaparelli has been confirmed and various measurements of them have been made. The clouds projecting beyond the limb and terminator, discovered at the Lick Observatory, have been studied, and their height has been found to be at least twenty miles. The relative colors of different portions of the planet have been minutely observed. Two large dark blue areas have been detected, and other portions have been noticed to be subject to gradual changes of color.

Many new double stars were found in a survey of the heavens south of — 30°, between 12^h and 18^h. The August occultation of Jupiter was observed both visually and photographically, as was also the new star in Auriga, and Swift's comet, the photographs of which showed detail not noticeable in the visual observations.

With the camera, having the aperature 2½ inches, very satisfactory photographs have been obtained of the Magellanic clouds, showing their composition to be partly of stars and partly of nebulous matter; also the spiral structure of the larger of the two clouds.

Meteorological observations are regularly carried on. Stations have been established at Mollendo, 100 feet above sea level, at La Joya, the elevation of which is 4150 feet, at the observing station, 8060 feet high, at the Chachani Ravine, 16,650 feet high, where numerous miscellaneous observations have been made. Notwithstanding the great height of the last named station, it can be reached by a mule path, and a hut has been erected where the observers can pass the night. A survey of the Arequipa valley and neighboring mountains has been made, depending on two separate base lines. The heights of the mountains have been measured, and in some cases the result has been checked by a mercurial barometer.

THE BRUCE PHOTOGRAPHIC TELESCOPE.

This instrument, which if successful will be in many respects the most powerful in the world, is now rapidly approaching completion. The eight surfaces of its objective have been ground and polished so that it could be tested on a star. The results were satisfactory, although of course no definite opinion can be formed until the final corrections are applied. The focal length proved to be that desired within half of one per cent. Plans have been made and the foundations laid for a one story brick building with a sliding roof in which it will be erected during its trial in Cambridge. After this, it is proposed to send it to the Arequipa station in Peru.

Photographs have been taken with the transit photometer on 192 evenings, and when clear, throughout the entire night. With this instrument images are obtained of all stars brighter than the sixth magnitude which cross the meridian during the night. The value

Buildings and Grounds. — The urgent need by the Observatory of a fire-proof building to hold its large collection of photographic plates, has been pointed out in several successive reports. This want has at last been supplied by the following liberal contributions of the friends of the Observatory: —

A friend (Boston)	$500
A friend (New York)	500
Ames, Oakes A.	100
Beebe, E. Pierson	100
Bradlee, Miss Helen C.	100
Bremer, John L.	200
Brimmer, Martin	300
Coolidge, J. Randolph	100
Curtis, Charles P.	100
Edmands, J. Rayner	200
Endicott, William, Jr.	500
Forbes, John M.	200
Gardner, Mrs. John L.	1000
Gardner, John L.	500
Hemenway, Augustus	100
Hemenway, Mrs. Mary	500
Hudson, John E.	100
Hunnewell, H. H.	200
Kimball, David P.	200
Lawrence, Samuel C.	$100
Lee, Henry	500
Lowell, John	100
Mason, W. Powell	200
Nash, Nathaniel C.	100
Paine, Robert Treat	300
Parkman, George F.	500
Peabody, F. H.	500
Peabody, Oliver W.	100
Pickering, Edward C.	500
Salisbury, Stephen	100
Shattuck, George O.	100
Thayer Brothers	200
Warren, Samuel D.	200
Weld, William F.	100
Wheelwright, J. W.	100
	$9,200

About two thirds of the total amount required has thus been provided. Unless future subscriptions are received the remainder must be taken from the sum available for the current expenses of the Observatory. A brick building, thirty by sixty feet, and having two stories and a basement has been erected and is now nearly completed. It will furnish a permanent storehouse for the glass photographs and the more valuable manuscripts of the Observatory, and also room for their examination and discussion.

The inadequate accommodation afforded by the East Wing of the Observatory, which is used as a dwelling house by the Director, has long been recognized. An arrangement has been made during the past year by which the amount deducted from the salary of the Director on account of his occupancy of the house is hereafter to be applied to the expenses of the Observatory instead of to those of the University at large. An extension has been made, at the expense of the Director, by which the accommodation for visiting astronomers and the rooms for entertaining them will be greatly improved. A large amount of grading has been done in connection with these buildings, and the hollow formed by the old entrance from Concord Avenue has been filled.

Publications. — Volume XV., Part II. of the Annals of the Observatory has been completed by the printing of the introduction. This work contains the zone catalogue of stars between the declinations + 49° 50′ and + 55° 10′, and concludes Volume XV. It will soon be distributed. Volume XIX., Part II., is in type as far as page 314. It contains a discussion of the zodiacal light by Professor Searle, and a determination of the atmospheric absorption by means of photography. Volume XXV. is in type as far as page 356. It contains a comparison of the places of stars in the zone + 49° 50′ to + 55° 10′ as determined by Professor Rogers, with the places of the same stars in previous catalogues, the results thus obtained for proper motion, and the separate results in right ascension and declination derived from the successive observations of the zone stars. Volumes XXIII., Part II., XXVI., Part II. and XXVIII., are not yet undertaken. Volume XXIX. will consist of comparatively brief, disconnected articles, like Volume XVIII. Three numbers of this volume are in type. They relate respectively to meteorological observations by Messrs. A. Lawrence Rotch and Winslow Upton at the time of the total solar eclipse of January 1, 1889, which they observed at Willows, California; to the determination of the longitude of Smith College, made in 1888, by Miss Mary E. Byrd and Professor Mary W. Whitney; and to photometric observations of asteroids, by Mr. Henry M. Parkhurst, in continuation of his previous article in Volume XVIII. upon the same subject. The fourth number of Volume XXIX. is also by Mr. Parkhurst, and relates to his observations of variable stars. Twenty pages of this article are in type, extending to page 111 of the entire volume. Volume XXX., Part III., containing meteorological observations of the Blue Hill Observatory, has been printed and will soon be distributed; Part IV. is required to complete the volume. Volume XXXI., Part I. has been printed and will soon be distributed; Part II. is ready for printing. This volume contains observations and essays by members of the New England Meteorological Society, during the years 1890 and 1891. Volume XL., Part I., has been printed and is soon to be distributed. It continues the publication of the work of the Blue Hill Meteorological Observatory from Volumes XX. and XXX., and contains observations made during the year 1891. The volumes bearing numbers between XXXI. and XL. have not yet been undertaken.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-sixth Annual Report of the Director of the Astronomical Observatory of Harvard College. Cambridge, 1891.

A Large Southern Telescope. Circular describing the advantages of establishing such an instrument at Arequipa, Peru.

Astronomical Possibilities at considerable altitudes. By W. H. Pickering. Astronomische Nachrichten, cxxix. 97. Reprinted in the Observatory, xv. 283.

An investigation of the systems of Bright Streaks visible upon the Full Moon. By W. H. Pickering. Astronomische Nachrichten, cxxx. 225.

Are there at present Active Volcanoes upon the Moon? By W. H. Pickering. The Observatory, xv. 250.

The Mountain Station of the Harvard College Observatory. By W. H. Pickering. Astronomy and Astro-Physics, xi. 353.

The Boyden Station of the Harvard College Observatory. By W. H. Pickering. Astronomy and Astro-Physics, xi. 357.

Colors Exhibited by the Planet Mars. By W. H. Pickering. Astronomy and Astro-Physics, xi. 449.

The Earthquake for February 23, 1892. By W. H. Pickering. Astronomy and Astro-Physics, xi. 470.

Colors Exhibited by the Planet Mars. By W. H. Pickering. Astronomy and Astro-Physics, xi. 545.

The Planet Saturn and its Satellites. By W. H. Pickering. Astronomy and Astro-Physics, xi. 649.

Mars. By W. H. Pickering. Astronomy and Astro-Physics, xi. 668.

The Glacial Period and the Planet Mars. By W. H. Pickering. Knowledge, xv. 113.

Can a Planet absorb its Oceans without having its Surface Temperature lowered? By W. H. Pickering. Knowledge, xv. 193.

Observations of Comet 1891 V. By O. C. Wendell. Astronomical Journal, xi. 56.

Second series of Observations of Comet 1891 V. By O. C. Wendell. Astronomical Journal, xi. 61.

Orbit of Comet 1891 IV. By O. C. Wendell. Astronomy and Astro-Physics, xi. 87.

Ephemeris of Comet 1891 IV., for March. By O. C. Wendell. Astronomy and Astro-Physics, xi. 251.

Observations of Comet a 1892. By O. C. Wendell. Astronomical Journal, xi. 158.

Orbit of Comet a 1892. By O. C. Wendell. Astronomy and Astro-Physics, xi. 443.

Observations of Comets 1891 II. and 1891 V. By O. C. Wendell. Astronomische Nachrichten, cxxx. 45; also Astronomical Journal, xi. 191.

Observations of Comets a 1892 and c 1892. By O. C. Wendell. Astronomical Journal, xi. 191.

Second Orbit of Comet a 1892. By O. C. Wendell. Astronomy and Astro-Physics, xi. 536.

Ephemeris of Comet a 1892 for August. By O. C. Wendell. Astronomy and Astro-Physics, xi. 625.

Second series of Observations of Comet a 1892. Also Observations of Comet c 1892. By O. C. Wendell. Astronomical Journal, xii. 94.

New Variable Stars in the Southern Sky. By M. Fleming. Astronomische Nachrichten, cxxx. 125.

Stars having Peculiar Spectra. By M. Fleming. Astronomy and Astro-Physics, xi. 418.

Astronomical Expedition to Peru. By M. Fleming. Publications of the Astronomical Society of the Pacific, No. 22, 58.

Distribution of Energy in Stellar Spectra. By Edward C. Pickering. Astronomische Nachrichten, cxxviii. 377. Reprinted in Astronomy and Astro-Physics xi. 22.

On the New Star in Auriga. By Edward C. Pickering. Astronomische Nachrichten, cxxix. 111.

A New Variable Star in Aries. By Edward C. Pickering. Astronomische Nachrichten, cxxxi. 62.

The Objective Prism. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 199.

The New Star in Auriga. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 228.

A change in the Spectrum of Nova Aurigae. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 330.

Nova Aurigae. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 417.

Nova Aurigae. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 750.

A New Variable Star. By Edward C. Pickering. Astronomy and Astro-Physics, xi. 752.

EDWARD C. PICKERING, *Director*.

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REPORT.

To the President of the University:

Sir, — The most important event to be mentioned in the present report is the completion of the new fire-proof brick building, and the transfer to it of about 30,000 stellar photographs. The second expedition to our Peruvian observing station has returned, and the third expedition has begun work successfully. The entire income of the Paine Fund, one of the largest gifts ever made to astronomy, is this year for the first time available for the use of the Observatory. Notwithstanding this important increase in our resources, the expenses due to additional work undertaken have also become greater, so that no new researches can be begun for the present. The addition to the Paine Fund will, however, compensate for the loss that this Observatory, like other American observatories, has suffered by the action of the U. S. Naval Observatory in depriving them of income from the sale of time signals. The expense of the second Peruvian expedition proved much greater than was anticipated, and has caused a considerable deficit in the Boyden Fund. The expenses for publication which are to be paid from the unrestricted portions of the income of the Observatory are likely to be large in coming years, and if possible a portion of the income should be reserved for a building fund, which will soon be required if the Observatory maintains its present rate of growth. The Observatory was represented at the Chicago Exhibition by a collection of about 250 photographs, and portraits of Bond, Paine, Boyden, and Draper.

Observatory Instruments.

East Equatorial. — The systematic observation of variable stars upon the system described in the last report continues to be the principal work of this instrument; but the photometric observation of the eclipses of Jupiter's satellites and the observation of comets are also carried on as before. The observer was Mr. O. C. Wendell, except that 9 of the 25 eclipses of Jupiter's satellites, photometric measurements of which were obtained during the year, were observed by the Director. The wedge photometer was used in 48 series of observations, comprising 3354 measurements, for determining the brightness of 1118 stars occurring in the Durchmusterung. Comet 1892 III. was observed 21 times for position, and was photometrically measured on 13 nights. Comet 1893 I. was observed 3 times, and Comet 1893 b 11 times, for position; the last was photometrically measured on 3 nights. One observation of the position of Comet 1893 c was also made. About 4000 measurements were made with the polarizing photometer, including (1) determinations of the relative light of the components of 65 of the brighter double stars, (2) determinations of the brightness of variable stars, including the new star in Auriga, which was observed on 8 nights, and (3) determinations of the brightness of faint comparison stars near circumpolar variables. The selection of these stars and the measurement of their positions also formed part of the work. Comparison stars selected from the Durchmusterung for a series of 60 variables have now been revised; one third of this work was done during the past year. Over 200 relative and as many absolute estimates of the brightness of variable stars were obtained, principally when they were faint; also 35 relative and as many absolute estimates of the brightness of the new star in Auriga. Some miscellaneous observations were likewise made.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision. The catalogue of the zone between the declinations + 49° 50′ and + 55° 10′ has been published and distributed, forming Volume XV., Part II., of the Annals of the Observatory. Volume XXV., containing the comparison of the positions in this catalogue with those of the same stars in previous catalogues, the resulting proper motions, and the comparison of the separate observations of each star with each other, has also been published. The printing of the journal of the zones is to be undertaken at once.

The reduction of the observations of the southern zone between the declinations — 9° 50′ and — 14° 10′ has been continued through the year. The work is complete with respect to the fundamental stars, except so far as it may be affected by the publication of their final places derived from observations elsewhere. Much work has also been done in reducing the observations of the zone stars. Observations of β Persei and the comparison stars proposed for it by Dr. Chandler were made on 10 nights, and the results were published in Volume XXIX. of the Annals of the Observatory.

Meridian Photometer. — Good progress has been made in the reduction of the photometric observations of the southern stars made in Peru by Professor S. I. Bailey. A portion of the catalogue is in type and the remainder is ready for the printer. Observations have been made by the Director with the meridian photometer on nearly every clear evening during the past year. The number of series is 107, and of separate photometric comparisons 46,272. The observations ordinarily last from seven to eleven in the evening; but last summer they were extended to one or two o'clock in the morning in order to complete the observation of the large number of stars in the Milky Way which can only be observed at that season. The observing list contains about 6000 stars, including the 4000 contained in the Harvard Photometry, which are thus reobserved. About three quarters of the observations required to complete this list, each star being observed on at least 3 nights, have now been made.

West Equatorial. — Mr. W. M. Reed made observations with this instrument on 87 evenings; these observations include 489 on variable stars, 1318 on comparison stars (among which are 178 made with the prismatic photometer mentioned in former reports), and 10 on the brightness of the comet discovered by Holmes. Meteors were seen passing through the field of the telescope on 25 occasions, and a record has been kept for 2 years of these phenomena, stating their place, movement, color, and other circumstances connected with them. 9 observations of aurora seen at Cambridge were made on 8 evenings.

HENRY DRAPER MEMORIAL.

The number of objects having peculiar spectra, which are annually discovered by Mrs. Fleming in her examination of the Draper photographs, has not diminished. The most important of these objects is a new star in the constellation Norma, whose spectrum was photographed at the Arequipa station on July 10, 1893, and of which no trace was visible on 13 plates taken from June 6, 1889, to June 21, 1893. Its spectrum appears to be identical with that of the new star which appeared in Auriga in December, 1891. 7 variable stars, T. Cassiopeiae, S Geminorum, T Geminorum, S Virginis, V Bootis, R Piscis Austrini, and S Aquarii, in addition to the 47 previously announced, have the hydrogen lines bright in their photographic spectra. 3 new variables have been discovered this year by means of this property. The number of stars of the fifth type has been increased by 10, making the total number now known of these objects 55. The hydrogen line F has been discovered to be bright in the spectra of BD. — 13° 893, magn. 5.8, and — 10° 1786, magn. 7.3. 10 stars have been shown to have spectra of the fourth type.

All of the spectrum plates have been carefully examined for the detection of objects of interest. The spectra of 20,149 stars on

190 plates having 60 minutes exposure have been classified for a revision and extension of the Draper Catalogue to include fainter stars and cover the entire sky. The number of photographs taken with the 8 inch Draper telescope is 2424; with the 11 inch, 1037. The latter include 213 photographic images of the spectrum of β Aurigae, 145 showing the principal lines double. The lines are double in 4 of the 94 photographs of ζ Ursae Majoris.

BOYDEN DEPARTMENT.

The second Peruvian expedition, under the direction of Professor W. H. Pickering, returned to Cambridge last spring after successfully observing the Total Eclipse of the Sun on April 16, 1893. Surveys were made which determined the positions and altitudes of various points in the Sorata range in Bolivia, and of Mt. Aconcagua in Chile. The most important astronomical work undertaken was the study of the members of the solar system by means of the 13 inch Boyden telescope. This included a study of the lunar rills and of variable spots upon the Moon and catalogues of them; of the diameters of the satellites of Jupiter, of their elongated shapes, the inclination of their axes of form, their axes of rotation, their markings, and the determination of the retrograde rotation of the first satellite; also a study of the markings of the planet Neptune. A series of measurements was also made of the double star α Centauri. These observations confirm the conclusion that the atmospheric conditions at Arequipa are particularly favorable for astronomical observations. It is extremely important that we should avail ourselves of the opportunities thus afforded by erecting at this station a telescope of the largest size. If this cannot be done, a telescope of 20 or 25 inches aperture would add greatly to our present knowledge of the surfaces of the planets and of other objects for which great magnifying powers are required. It is hoped that this matter will be borne in mind by those who wish by their gifts to advance astronomical science. The number of photographs taken with the 8 inch telescope was 250; with the 13 inch, 112. These numbers would be greater but that the cloudy season is included in the portion of the year here under consideration.

The third expedition, under the direction of Professor Solon I. Bailey, began work on April 4, 1893. Since then 1516 photographs have been taken with the 8 inch telescope and 852 with the 13 inch telescope. An eyepiece has been attached to the latter instrument so that the motion of the telescope may be controlled by an image formed by its own objective, thus dispensing with a finder. Very remarkable photographs have thus been obtained of the principal southern clusters. On a photograph of ω Centauri over 7000 stars were counted by Professor Bailey in a region 30′ square. 2 of these stars have been found to be variable, 1 being discovered by Mrs. Fleming, the other by the Director. Professor Bailey has shown that 3 stars are variable in the cluster 47 Tucanae. The images of the stars in these clusters are almost perfectly circular, although the exposure in some cases exceeded 3 hours. 104 photographs have been obtained with the 2½ inch Voigtländer doublet. The brightness of about one half of the stars south of declination —30, and brighter than the magnitude 6.3, has been determined visually.

Until recently the highest meteorological station in the world has been that established by this Observatory on Mt. Chachani at an elevation of 16,650 feet, After making a careful examination of the volcano El Misti, Professor Bailey has succeded in establishing a station upon its top at an elevation of 19,200 feet. A path has been constructed by which mules have been led to the summit, and beside the meteorological shelter a wooden hut has been built upon the summit. A survey of the craters has been made, and a stone hut has been erected on the side of the mountain at a height of 15,600 feet. The temperature, pressure, moisture, and the velocity and direction of the wind are now being recorded at the summit station by self registering instruments. The sheets are changed at intervals, thus giving a record of atmospheric conditions at a height hitherto unattempted. The use of beasts of burden at these heights offers an opportunity in the future of carrying instruments and conducting experiments at altitudes heretofore regarded as inaccessible for these purposes. The mountain as seen from every direction is an isolated sharp peak. It is therefore especially suited for the study of the upper atmosphere.

THE BRUCE PHOTOGRAPHIC TELESCOPE.

This instrument is now nearly completed, and photographs will be taken with it in a few days. So far as can be judged at present it seems likely to accomplish all that has been expected of it. The brick building with sliding roof to contain this instrument is finished and a large part of the mounting is in place.

Photographs have been taken with the Bruce transit photometer on 154 evenings, and when clear, throughout the entire night. A large part of them have been identified so that they will be immediately available, if required as in the case of the new star in Auriga. Good progress has also been made with the measurement of the forty thousand stars of the tenth magnitude which are being selected for standards for faint stellar magnitudes.

MISSCELLANEOUS.

Zodiacal Phenomena. — An effort has been made to obtain observations as nearly contemporaneous as practicable, and made at widely separated points, of the distribution of light in the zodiac, and particularly of the slight maximum of light nearly opposite the Sun, known as Gegenschein or Counterglow. Professor Barnard, of the Lick Observatory, kindly undertook to coöperate in this work, as did also Professor Bailey at Arequipa. Accordingly, during moonless nights in September, 1893, 36 observations were obtained; 13 of them by Professor Barnard, 3 by Professor Bailey and 20 by Professor Searle and Mr. Reed at Strafford, Vermont. Mr. A. E. Douglass also made some observations at Cambridge, notwithstanding the interference of the number of electric lights in this vicinity. The corresponding numbers of observations in October were 9, 3, and 35; the last were made by Messrs. Douglass and Reed, largely at Blue Hill, but partly at Cambridge and elsewhere. The conclusion of most immediate interest is that resulting from the comparison of the positions of the maxima of light observed at the different stations. In these no effect of parallax can be discerned.

Library. — The library of the Observatory has been increased during the year by the addition of 294 volumes and 715 pamphlets. The total numbers of volumes and pamphlets on November 1, 1893 were 7492 and 9460 respectively.

As the station at Arequipa, Peru, will be maintained permanently, it is desirable, owing to its remoteness, that it should have a library of its own. Copies of astronomical and meteorological works sent thither direct, or through this Observatory, will be gratefully received and will prove of much value.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued as in past years, although Mr. Ritchie has resigned his position as Assistant in the Observatory. Astronomers are requested to continue to send to this Observatory announcements of their discoveries for transmission to the observatories of Europe and America.

Buildings and Grounds. — On March 2, 1893, a transfer was made of a large portion of the contents of the west wing of the main building of the Observatory to the new brick building. Nearly thirty thousand glass photographic plates were transferred from one building to the other without serious accident. The greater number of the plates measured eight by ten inches, and the total weight of the glass was about eight tons. A rope was stretched from the old building to the new, and boxes each containing one hundred plates were attached to a pulley and allowed to run down. They were thus transferred at the rate of about six thousand an hour. Apart from the importance of protecting the photographs from injury, the new building proves of the greatest convenience in providing additional room for their examination, and for the corps of computers engaged in their study. The alterations in the residence made by the Director have been completed, and afford much additional space for the accommodation and entertainment of visiting astronomers.

Certain observations at Cambridge are each year rendered more difficult. The introduction of electric lights, especially in the vicinity of the Observatory, greatly interferes with the observation of faint objects. Additional trouble is anticipated from the proposed introduction of electric cars on Concord Avenue, which forms the southern boundary of the grounds of the Observatory. A more serious difficulty is apprehended from the proposed widening of Concord Avenue, which, if carried out, would bring the cars still nearer the instruments, and would necessitate cutting down the row of large spruce trees by which the instruments are now partially protected from the dust of the road. The citizens of Cambridge and the friends of the Observatory should be alike interested in saving this fine collection of trees from destruction.

Publications. — The following volumes in the series of Annals of the Observatory, some of which were mentioned last year as nearly complete, have been published and distributed: XV., Part II., XIX., Part II., XXV., XXIX., XXX., Part III., XXXI., Parts I. and II., and XL., Part I. Volume XL., Part II., has also been published and distributed. It contains the Blue Hill Meteorological Observations for 1892. The series of volumes is now complete to Volume XXII. inclusive. Volumes XXIII., Part II., XXVI., Part II., and XXVIII. are not yet undertaken. Volume XXIX., above mentioned as published, was completed by the addition of articles on the magnitude of bright stars north of $+70°$, and on meridian circle observations of β Persei. Volume XXX., Part IV., is not yet published. Volume XXXIV. has been begun and 112 pages are in type. It contains the results of the observations of the brightness of the southern stars made with the meridian photometer by Professor Bailey. Volume XLI. has also been begun, and 19 pages are in type. It will contain annual summaries of observations made by the New England Weather Service, to which the similar work of the New England Meteorological Society has been transferred. The summary

for 1892 is almost completed. Thirty-two pages of meteorological observations made in Peru have also been printed. They have not yet been assigned to a volume.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-seventh Annual Report of the Director of the Astronomical Observatory of Harvard College. Cambridge, 1892.

A Large Southern Telescope. Circular issued last year and reprinted in Astronomy and Astro-Physics, xi. 783.

Publications and Photographic Illustrations issued by the Observatory of Harvard College. Cambridge, 1893.

The Astronomical Observatory of Harvard College. Circular describing the stations, instruments, and publications of the Observatory. Cambridge, 1893.

Improved Methods of Observing the Zodiacal Light. By Arthur Searle. Astronomische Nachrichten, cxxxii. 163.

Lunar Atmosphere and the Recent Occultation of Jupiter. By W. H. Pickering. Astronomy and Astro-Physics, xi. 778.

Mars. By W. H. Pickering. Ibid. xi. 849.

The Planet Jupiter and its Satellites. By W. H. Pickering. Ibid. xii. 193.

Jupiter's Satellites. By W. H. Pickering. Ibid. xii. 390.

The Rotation of Jupiter's Outer Satellites. By W. H. Pickering. Ibid. xii. 481.

Polar Inversions of the Planets and Satellites. By W. H. Pickering. Ibid. xii. 692.

Plato. By W. H. Pickering. The Observatory, xvi. 175.

El planeta Saturno y sus satélites. W. H. Pickering. La Gaceta Cientifica, Publicacion mensual de la Sociedad "Amantes de la Ciéncia." [Lima, Peru.] Año. ix. pp. 25–28.

ω Centauri. By Solon I. Bailey. Astronomy and Astro-Physics, xii. 689.

Observations of Comet 1893 I. By O. C. Wendell. Astronomische Nachrichten, cxxxi. 167.

Observations of Comet 1892 III. By O. C. Wendell. Astronomical Journal, xii. 119.

Observations of Comet g 1892. By O. C. Wendell. Ibid. xii. 128.

Second series of Observations on Comets f and g 1892. By O. C. Wendell. Ibid. xii. 142.

Ephemeris of Comet 1892 VI. By O. C. Wendell. Astronomy and Astro-Physics, xii. 85.

Observations of Comets a, d, e, and f 1892. By O. C. Wendell. Astronomical Journal, xii. 157.

Note on Comet 1893 II. By O. C. Wendell. Astronomy and Astro-Physics, xii. 660.

Stars having Peculiar Spectra. By M. Fleming. Ibid. xi. 765.

Stars having Peculiar Spectra. By M. Fleming. Ibid. xii. 170.

Stars having Peculiar Spectra. By M. Fleming. Ibid. xii. 546.

A Field for Woman's Work in Astronomy. By M. Fleming. Ibid. xii. 683.

Stars that have been found variable in the Photograph. By W. M. Reed. Astronomical Journal, xiii. 62.

Swift's Comet. By A. E. Douglass. Astronomy and Astro-Physics, xii. 202.

The Balance Roof for Telescope Buildings. By A. E. Douglass. Ibid. xii. 207.

Indications of a Rainy Period in Southern Peru. By A. E. Douglass. Science, xx. 231.

A Useful Bath. By A. E. Douglass. Anthony's Photographic Bulletin, xxiii. 654.

Peculiar Stellar Spectra. By E. C. Pickering. Astronomy and Astro-Physics, xi. 945.

Work for Large Telescopes. By E. C. Pickering. Ibid. xii. 114.

The Constitution of the Stars. By E. C. Pickering. Ibid. xii. 718. Reprinted in the Scientific American, October 21, 1893.

New Variable Star in Carina. By E. C. Pickering. Astronomical Journal, xiii. 79.

Roberts' Variable in Carina. By E. C. Pickering. Ibid. xiii. 147.

EDWARD C. PICKERING, *Director.*

FORTY-NINTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR ELEVEN MONTHS ENDING SEPTEMBER 30, 1894.

BY

EDWARD C. PICKERING.

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY.
1894.

BIBLIOTHECA BODLEIANA

REPORT.

To the President of the University:

Sir, — The present report relates to the period of eleven months beginning November 1, 1893, and ending September 30, 1894. Hitherto the reports of the Observatory have taken date on the first of November of each year, but to bring them more nearly into conformity with the practice of other departments of the University a change has been made this year to the first of October. The most important events of the year have been the practical trial of the Bruce telescope and the successful operation for several months of the Boyden meteorological station on the summit of the Misti, at a height of 19,200 feet. The Observatory is indebted to Mr. Z. A. Willard for a valuable gift, an astronomical clock, constructed by Simon Willard, Jr., of Boston. The subterranean vault intended as a clock room by Professor Bond has been reopened, and if it can be rendered sufficiently dry the clock will be placed there. It is expected that the accuracy of our time signals will thus be materially increased.

An incident to be regretted has been a series of criticisms of the photometric work of the Observatory, which has been published during the year in local newspapers and other periodicals. So far as these criticisms have a scientific character they are answered below. A larger amount of space than usual has therefore been assigned to the description of the work of the meridian photometer, although it constitutes only about one-tenth of the entire work of the institution.

OBSERVATORY INSTRUMENTS.

East Equatorial. — The systematic observation of variable stars upon the system described in previous reports continues to be the principal work of this instrument; but the photometric observation of the eclipses of Jupiter's satellites and several other classes of observation are also carried on as before. The observations were made by Mr. O. C. Wendell, except those of 3 of the 21 eclipses observed photometrically during the year, which were made by the Director. The total number of eclipses already observed is 546. The wedge photometer was used in 36 series of observations, comprising 1680 measurements, for determining the brightness of 560 stars occurring in the Durchmusterung. About seven thousand measurements were made with a polarizing photometer, including determinations of the relative light of the components of 53 of the brighter double stars; determinations of the brightness of variable stars; and measurements to extend the photometric scale to faint stellar magnitudes, relative estimates being also made for the same purpose. In addition to this, a series of measurements has been begun on some southern double stars whose combined light was determined with the meridian photometer at the Arequipa Station. Over four hundred relative estimates of variable stars have been made, and between one and two hundred absolute estimates, principally when the stars were faint. The regular observation of seventeen circumpolar variables has been continued as in past years, and the scheme is gradually being extended to all the known variables of long period.

Meridian Circle. — The reduction of the observations made with this instrument by Professor William A. Rogers continues under his supervision, and that portion of the work relating to the zone between the declinations + 49° 50′ and + 55° 10′ has been completed. Volume XXXV. of the Annals of the Observatory, containing the first half of the journal of the zones, has been printed, and a second volume, to contain the remainder of this journal, will be printed during the coming year. The observations of fundamental stars, made in the years 1880 to 1883 inclusive, are largely reduced, and will probably be published within two years more. This will complete the publication of the work done by Professor Rogers with the meridian circle.

The reduction of the observations of the southern zone between the declinations — 9° 50′ and — 14° 10′ has been continued through the year. Investigations have been made with regard to systematic errors in the observations of the fundamental stars, dependent upon declination and upon magnitude, but for the present these investigations cannot be completed, since their results will be somewhat affected by the future publication of the definitive places of the fundamental stars, from observations made at other observatories. Provisional constants, therefore, determined without regard to the investigations just mentioned, are employed in the preliminary reduction of the zone stars, which will be sufficiently precise to indicate the stars requiring additional observations. The portions of this reduction which are now complete for the entire series of observations are as follows: — The observed times of transit, reduced to the central line of the middle tally; the means of the microscope readings, corrected for error of runs; the reduction to the centre of the field required by the transits over the inclined lines used in the observations for declination; and the correction for the curvature of the paths of the stars through the field, known as the reduction to the meridian. The meteorological terms of the correction for refraction have also been computed throughout. The work recently in progress has been the completion of the reductions for January, February, and March of each year, in the hope that this may be finished in season to allow observations for revision to be undertaken early in 1895.

Observation of β Persei and a series of other stars near it in right ascension were made on seventeen nights during the winter, and the reduction of these observations is approaching completion.

Meridian Photometer. — The reduction of the photometric measures of the southern stars observed by Professor S. I. Bailey in Peru, is now completed, and the catalogue containing the resulting magnitudes is in print. Observations have been made by the Director with the meridian photometer during about four hours on nearly every clear evening. The total number of series is 110, and of separate photometric settings 54,360. The observations of the first investigation undertaken with this instrument since its return from Peru are nearly completed. About six thousand stars have each been observed on at least three evenings. This catalogue includes all the stars of the Harvard Photometry, eighty lists of comparison stars for variables of long period, and various stars whose magnitude is desired by other astronomers. A study has been made of the atmospheric absorption, especially for very low stars, and its coefficient has been derived on each evening both for the southern and the northern stars. These values are now applied as corrections to the individual observations instead of adopting a mean value of the absorption. A new working list has been prepared of the stars north of —40° whose magnitude according to the best authorities is 7.5 or brighter, and which have not already been observed with the meridian photometer. This list contains about fourteen thousand stars, of which about two thousand have been observed during the last year.

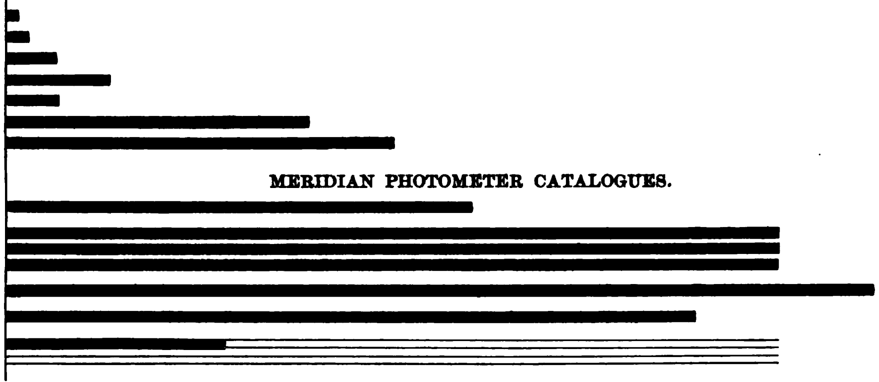
An attempt has recently been made by Mr. S. C. Chandler to prove that the photometric observations made with the meridian photometer have little value. (Astron. Nach. Vol. 134, p. 355, and Vol. 136, p. 85.) It appeared that certain variable stars were incorrectly identified and observations of faint adjacent stars were obtained when the variables were too faint to be seen with this instrument. He claimed that erroneous observations were made in the case of fifteen out of eighty-six variable stars, and from this drew the extraordinary inference that similar errors affected the entire catalogue of twenty thousand stars contained in the same volume, although nearly all of the latter stars were bright enough to be readily measured, and identified with certainty. The most complete answer to this criticism is the extensive comparison recently made at the Potsdam Observatory of the photometric magnitudes obtained at that institution with those obtained here. Since this comparison is based on a large number of ultimate determinations obtained at both observatories it seems to dispose of inferences drawn from a few cases of exceptional difficulty. The Potsdam astronomers state that only four catalogues of the brightness of the stars are complete and correct enough for comparison with their own results. These are the Durchmusterung, the Uranometria Oxoniensis, and the Harvard results given in Volumes XIV. and XXIV. As was to be expected, the Durchmusterung magnitudes proved to be much less accurate than those in either of the other catalogues. The numbers of stars contained in each of the three photometric catalogues which were also observed at Potsdam are Oxford, 691, Harvard XIV., 791, and Harvard XXIV., 801. After applying a correction for color, the numbers of stars in these three catalogues whose brightness differs by half a magnitude or more from the Potsdam values, are 21, 6, and 13 respectively. For this and other reasons it was concluded at Potsdam that the order of accuracy of the results of the three catalogues is first Harvard XIV., second Harvard XXIV., and third Oxford. (Potsdam Publications, Vol. IX., p. 501.) The minimum number of nights' observation on which the results of Harvard XIV. depend is three, of Harvard XXIV. two. A comparison has been made at this observatory of the various magnitudes of the 40 discordant stars named above, as given in the five catalogues, Oxford, Potsdam, Harvard XIV., Harvard XXIV., and the revision mentioned above of the Harvard Photometry. Taking means and residuals of the magnitudes of the stars contained in three or more of these catalogues, the average deviations become, when arranged in the order of their magnitudes, for Revised Harvard Photometry, 0.11, Harvard XIV., 0.15, Harvard XXIV., 0.18, Potsdam, 0.21, Oxford, 0.29. The number of cases in which each catalogue gives the greatest or least value is similarly for Revised Harvard Photometry, 5, Harvard XIV., 6, Harvard XXIV., 10, Potsdam, 19, Oxford, 20. The order in both cases is the same, and serves to indicate the relative accuracy of the results of these five catalogues, which is also shown graphically in Table I. In two cases only do the Harvard XIV. and Oxford measures differ more than half a magnitude. Numerous other tests give a similar result. (See Astron. Nach., Vol. 135, p. 217.)

TABLE I.—NUMBER AND MAGNITUDE OF DEVIATIONS.

Order of Excellence.	Catalogue.	Number.	Average Deviations.	Number of Extremes.
I.	Revised Harv. Phot.	. .	0.11	5
II.	Harvard XIV.	6	0.15	6
III.	Harvard XXIV.	13	0.18	10
IV.	Potsdam.	. .	0.21	19
V.	Oxford.	21	0.29	20

TABLE II.—NUMBER OF STARS IN VARIOUS PHOTOMETRIC CATALOGUES.

Catalogue.	Years.	Number of Stars.
Herschel.	1835–38	149
Seidel.	1844–60	208
Wolff I.	1869–75	475
" II.	1876–83	970
Peirce.	1872–75	494
Pritchard.	1881–85	2784
Potsdam.	1886–93	3522
Vol. XIV.	1879–82	4260
Vol. XXIII.–IV.	1882–88	20982
Vol. XXXIV.	1889–91	7922
Vol. XLIV. (?)	1892–94	6000±
Vol. LIV. (?)	1893–97(?)	14000±



It is maintained that the meridian photometer possesses the same advantages in measuring the light of a star that the meridian circle does in measuring its position. In both instruments absolute values are determined directly, and they are obtained very rapidly. Stars are identified in the same way in both, rapidly and accurately, and in both the systematic errors are small even if the accidental errors are in some cases larger than those resulting from other methods. Stars can be observed with the meridian photometer under favorable circumstances nearly at the rate of one a minute, and the average deviation of the results thus obtained does not generally exceed one-tenth of a magnitude. The amount of material accumulated by the meridian photometer is shown graphically in Table II., which gives for the principal photometric catalogues hitherto published, and for those in preparation here, the designation, the years of observation, and the number of stars contained in each.

West Equatorial. — Observations of variable stars were continued by Mr. W. M. Reed with this instrument until February 11, 1894, since which time he has carried on the same work with the five-inch telescope belonging to Abbot Academy at Andover, Mass., the use of which was kindly granted for the continuation of the observations. The plan of the work comprises the observation of as many of the variable stars of long period as possible through all stages of their brightness. When any of them become too faint to be seen with the instrument employed by Mr. Reed, he reports the fact to this Observatory, where the stars are observed, so far as practicable, by Mr. Wendell with the large equatorial until they recover sufficient brightness to be again observed by Mr. Reed. The number of nights on which Mr. Reed has made observations is 123; the number of observations of variable stars is 1641; of comparison stars, 339; of stars at the limit of visibility, 70.

In addition to this work on variable stars, Mr. Reed observed 6 reappearances of satellites of Jupiter, all at Cambridge, and 22 telescopic meteors. He looked for aurora on every clear night when observations with the telescope were in progress, and recorded its presence on 12 occasions. On 10 dates he observed the phenomenon of Gegenschein and studied the faint bands of light in the zodiac. The satisfactory condition of the air at Andover, and the skill of the observer, are shown by the fact that he obtained observations of Gegenschein as late as May 11. and again, after it had passed the Milky Way, as early as August 5. No previous observations, so far as is known, have been made so near the same part of the Milky Way, except at Arequipa.

HENRY DRAPER MEMORIAL.

The number of photographs taken with the 8-inch Draper telescope is 1657. The number taken in Peru with the 8-inch Bache telescope is 1708. All of the spectra photographed with these instruments have been examined by Mrs. Fleming. As a result seven variable stars, U Puppis, V Cancri, V Leonis, T Sagittarii, R Delphini, R Vulpeculae and R Phoenicis, have been shown to have the hydrogen lines bright in their photographic spectra. Unsuccessful attempts have been made to photograph the spectra of many other variables of long period when at maximum, and no image has been obtained. This has been found to be due in many cases to large errors in the ephemerides, and has been remedied by depending upon the observations of Mr. Reed and making the time of photographing each star depend upon its observed, instead of its predicted brightness. Eleven new variables have been discovered this year from the presence of bright hydrogen lines in their spectra, besides three whose variability was discovered from changes in their photographic images. The number of stars of the fifth type has been increased by seven, making the total number of these objects 62. Five gaseous nebulae have been discovered from their spectra. The hydrogen line H β has been discovered to be bright in the spectra of five stars, and twelve stars have been shown to belong to the fourth type. The spectra of A. G. C. 18049 and 22640 are peculiar. Several photographs have been obtained of the new star in the constellation Norma, whose discovery was mentioned in the last report. At the Lick Observatory it was shown from visual observations that its spectrum, as in the case of the new star in Auriga, had become that of a gaseous nebula. This has been confirmed from photographs taken at Arequipa, which also show that this object is now gradually becoming fainter. The spectra of 4557 stars on 30 plates have been classified for the new Draper Catalogue. On one of these plates covering the region of the variable star η Carinae, 1161 spectra have been measured.

The number of photographs taken with the 11-inch Draper telescope is 912. The lines in the spectrum of ζ Ursae Majoris are found to be double in 59 out of 340 images, and of β Aurigae in 47 out of 65.

An investigation has been in progress for some time for the detection of stars having large parallaxes or proper motions. Photographs are taken in the usual position with the film towards the object-glass, and also with the plate reversed, the photograph being taken through the glass. These are repeated at intervals of six months at the times when the effect of parallax on their right ascension would have its greatest value. Plates thus obtained may then be superposed so that the films shall be in contact and the two images of each star made to appear like a close double with components north and south. Small changes in position may be detected by changes in the position angle, and the amount of the parallax or proper motion may be measured with great accuracy. Several hundred stars have thus been shown to have no parallax exceeding half a second.

BOYDEN DEPARTMENT.

The meteorological station on the Misti was successfully conducted for several months, one of the assistants, generally Mr. Waterbury, visiting it every ten days and readjusting the self-recording instruments. Unfortunately, early in September, the shelter containing the instruments was found to have been broken into and a number of the instruments carried off. Apparently the robbery was committed by two Indians whose tracks were followed to a considerable distance. The property stolen would of course be of no use to the thieves and its intrinsic value would be a small part of the actual loss. The work at this station was conducted with great labor, a mule path had been built to the summit and the entire expenditure had been large. It will be a serious loss to science if it proves impossible to maintain the station.

The number of photographs obtained by Professor Bailey with the 13-inch Boyden telescope is 561, including some remarkable charts. Among them may be mentioned photographs of the Nebula of Orion with an exposure of eight hours, of the cluster ω Centauri with an exposure of six hours, and of η Carinae with exposures of six and fourteen hours respectively. In some of these, notwithstanding the long exposure, the image shows no deviation from the circular form. This is mainly due to substituting for a finder two eyepieces attached to the main telescope. One of them serves to follow a guiding star in the usual way, the other directed to another star shows if the plate needs to be rotated in its own plane. This appears to be an important improvement in making the best photographic charts of long exposure, especially of the polar regions. By the ordinary methods it is impossible to entirely correct such errors as those due to flexure and refraction, which do not depend upon the direction of the axis of the earth.

Attention should again be drawn to the importance of availing ourselves of the admirable atmospheric conditions at Arequipa. A telescope of the largest size would not only have most favorable opportunities for work, but a field unexplored with such an instrument in the southern sky. Much could be done with a smaller instrument, as is shown by the work already accomplished with the

13-inch Boyden telescope. Out of a list of thirty telescopes whose aperture exceeds 14 inches or more, but one is mounted south of latitude + 35° and this one is not in use. A moderate expense only would be required to carry out this plan.

THE BRUCE PHOTOGRAPHIC TELESCOPE.

A careful trial has been made of this instrument and 936 photographs have been obtained with it. The spectra of the faint stars prove very satisfactory and stars too faint to be photographed with the other instruments can thus be studied. Bright hydrogen lines have been found in the spectra of S Orionis, S Bootis, W Virginis and S Librae, and the spectrum of V Ophiuchi has been shown to be of the fourth type. The length of these spectra is about a quarter of an inch, which is sufficient to show much detail in the spectra of fairly bright stars. To study still fainter spectra a prism of crown glass and of smaller angle has been ordered. The absorption of the photographic rays is less for this material and it is expected that much fainter spectra can be photographed, since the dispersion will also be less. The contract has not yet been filled for the Bruce telescope, since difficulty is still experienced in making charts in which the images shall be circular. Experiments are in progress in this direction and it is hoped that the method described above as applied to the 13-inch Boyden telescope will prove equally successful with this instrument.

A variety of experiments has been made to determine the photographic magnitudes of the brighter stars on a uniform scale. It is now expected that this can be done with the transit photometer for stars brighter than the third magnitude, and that the scale can be extended to stars from the third to the sixth magnitude by a series of photographs which are being taken with a portrait lens having an aperture of 2.5 inches. The images are thrown out of focus and the intensity of the circular disks thus obtained can be accurately measured.

MISCELLANEOUS.

Library. — The library of the Observatory has been increased since the time of the last report by the addition of 218 volumes and 529 pamphlets. The total numbers of volumes and pamphlets on October 1, 1894, were 7710 and 9989 respectively.

As the station at Arequipa, Peru, will be maintained permanently, it is desirable, owing to its remoteness, that it should have a library of its own. Copies of astronomical and meteorological works sent there direct, or through this Observatory, will be gratefully received and will prove of much value.

Telegraphic Announcements. — The distribution of telegraphic announcements of discovery has been continued as in past years, although Mr. Ritchie has resigned his position as Assistant in the Observatory. Astronomers are requested to continue to send to this Observatory announcements of their discoveries for transmission to the observatories of Europe and America.

Temporary absence of Observers. — Leave of absence, without salary, was granted on April 1st, 1894, to Professor W. H. Pickering and Mr. A. E. Douglass, in order that they might join the Lowell Observatory in Arizona. The 12-inch telescope and its stand were leased to Mr. Lowell from May 1st. No connection, however, exists between the two observatories.

Buildings and Grounds. — Since the time of the last report, a line of horse cars has been established on Concord Avenue, which forms the southern boundary of the grounds of the Observatory. The passage of these cars has no material effect upon the observations made here, but it is feared that the introduction of electric cars, which has been proposed, would be more detrimental. The widening of Concord Avenue, proposed last year, has not thus far been effected, and it is hoped that in any future change of that kind some means may be found of preserving the row of trees mentioned in the last report.

The electric lights, which seriously interfere with the observation of faint objects such as comets, nebulae, and zodiacal phenomena, prove an advantage in one way. They render visible faint clouds, which are carefully looked for every few minutes when the meridian photometer is in use. The effect is like that of the Moon, but as the lights are below the clouds instead of above them the latter become conspicuous even when too faint to be seen in moonlight.

Exhibition of Photographs. — The photographs sent to the Chicago Exhibition were safely returned, and by request were sent to California for exhibition at the Midwinter Fair. By the courtesy and aid of the Harvard Club of San Francisco and of Professor Holden, Director of the Lick Observatory, the photographs were successfully arranged for exhibition and safely returned.

Publications. — The printing of the following volumes of Annals of the Observatory has been finished: XXXV., containing the first half of the zone observations made by Professor Rogers between the declinations + 49° 50′ and + 55° 10′; XL., Part III., containing the

Blue Hill Meteorological Observations for 1893; and XLI., Part I., containing a summary of observations made by the New England Weather Service in 1892. Volume XXXII., Part I., containing a discussion of photographic and visual observations by Professor W. H. Pickering is nearly completed. 201 pages of Volume XXXIV., which contains the observations by Professor Bailey of the brightness of 7922 southern stars, are in type. Volume XLI., Part II., containing a summary of observations made by the New England Weather Service in 1893, is in progress. A description of the meteorological station on El Misti appeared in two articles by Mr. A. Lawrence Rotch (American Meteorological Journal, X., 282, and XI., 187, 201); and a description by Mr. S. P. Fergusson of the pole star recorder in use here, appears in the same Journal, XI., 62.

Besides the volumes of Annals above mentioned, the following publications have appeared during the year: —

Forty-eighth Annual Report of the Director of the Astronomical Observatory of Harvard College. Cambridge, 1893.

The Ultra-Violet Hydrogen Spectrum. By W. H. Pickering. Astronomy and Astro-Physics, xii. 171.

The Total Eclipse of April 16th. By W. H. Pickering. Ibid. xii. 461.

Telescope Mountings and Domes. By W. H. Pickering. Ibid. xiii. 1. Reprinted in Observatory, xvii. 73.

A Study of Nova Aurigae and Nova Normae. By W. H. Pickering. Ibid. xiii. 201.

Melting of the Polar Caps of Mars. By W. H. Pickering. Ibid. xiii. 308. Reprinted in Observatory, xvii. 173.

The Forms of the Discs of Jupiter's Satellites. By W. H. Pickering. Ibid. xiii. 423.

The Seas of Mars. By W. H. Pickering. Ibid. xiii. 553.

Jupiter's First Satellite. By W. H. Pickering. Astronomische Nachrichten, cxxxv. 227.

South American Meteorology. By W. H. Pickering. American Meteorological Journal, X. 343.

The Arequipa Observations of Mars and Jupiter. By W. H. Pickering. Publications of the Astronomical Society of the Pacific, vi. 221.

Les Satellites de Jupiter. By W. H. Pickering. L'Astronomie, xii. 468.

The Harvard Observatory in Peru. By W. H. Pickering. Harvard Graduates Magazine, ii. 350.

A Climb in the Cordillera of the Andes. By W. H. Pickering. Appalachia, vii. 205.

Observations of Comets 1892 I, II, III, V, VI, also 1893 I, II. By O. C. Wendell. Astronomische Nachrichten, cxxxiv. 175.

Ephemeris of Comet 1893 IV for January, 1894. By O. C. Wendell. Astronomy and Astro-Physics, xiii. 80.

Ephemeris of Comet 1893 IV for March, 1894. By O. C. Wendell. Ibid. xiii. 255.

Ephemeris of Comet 1894 I for June, 1894. By O. C. Wendell. Ibid. xiii. 514.

A Convenient Naked-Eye Star Atlas. By O. C. Wendell. Popular Astronomy, ii. 47.

Stars having Peculiar Spectra. By M. Fleming. Astronomy and Astro-Physics, xii. 810.

Two New Variable Stars. By M. Fleming. Ibid. xiii. 195. Popular Astronomy, i. 324.

Stars having Peculiar Spectra. By M. Fleming. Ibid. xiii. 501.

Stars having Peculiar Spectra. By M. Fleming. Astronomische Nachrichten, cxxxv. 195.

A New Star in Norma. By E. C. Pickering. Ibid. cxxxiv. 101. Astronomy and Astro-Physics, xiii. 40. Reprinted in Publications of the Society of the Pacific, vi. 53.

The New Star in Norma. By E. C. Pickering. Astronomische Nachrichten, cxxxiv. 181.

Anderson's Variable in Andromeda. By E. C. Pickering. Ibid. cxxxiv. 347.

Maximum of χ Cygni. By E. C. Pickering. Ibid. cxxxv. 127.

Variable Stars near 47 Tucanae. By E. C. Pickering. Ibid. cxxxv. 129.

New Variable Stars in Sculptor, Scorpius, Ophiuchus and Aquila. By E. C. Pickering. Ibid. cxxxv. 161.

The Photometric Catalogues of the Harvard College Observatory. By E. C. Pickering. Ibid. cxxxv. 217.

New Variable Star in Carina. By E. C. Pickering. Astronomical Journal, xiii. 79.

New Variable Star in Carina. By E. C. Pickering. Ibid. xiii. 147.

The New Star in Norma. By E. C. Pickering. Ibid. xiii. 398.

Photographic Determination of Stellar Motions. By E. C. Pickering. Ibid. xiii. 521.

The Astronomical Observatory. By E. C. Pickering. Harvard Graduates Magazine, ii. 241.

The Astronomical Observatory. By E. C. Pickering. Ibid. ii. 394.

The Astronomical Observatory. By E. C. Pickering. Ibid. iii. 87.

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